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"Crafted for the Digital World: Digitally Realistic Costumes in CG Feature Films"

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Abstract

The growth of computer-generated (CG) effects in live-action films has gradually expanded to the creation of digital characters and costume design. In many contemporary films, all aspects of characters and costumes are built digitally. Yet very little is known about the process of designing digital costumes, nor is there a critical theoretical examination of the areas emerging from the practice. This article explores digital costume design development using the CG feature films *Avatar* and *Avatar: The Way of Water* as case studies. The data consists of interviews with the films' costume designer, Deborah L. Scott, and comparative analysis of the costume renderings, physical materials from the design development process and their digital reproductions. The study enlightens how the physical costume fabrication process and motion testing are integrated into designing digital costumes and how designs evolve during their digital creation. The article sheds light on the creative opportunities digital costume design poses and provides important grounding for further research on the wider range of theoretical areas related to digital costume design.

Keywords: digital costume, costume design, digital characters, computer-generated imagery, multisensorial, perceptual realism

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Crafted for the Digital World

Digitally Realistic Costumes in CG Feature Films

Introduction

Over the past 20 years, computer-generated (CG) effects have gradually expanded from the creation of imaginative environments and supplementing scenes with special effects to the construction of special digital features in characters and costumes. The effects initially had no influence on the creation of costumes. However, the growth of CG implementation in live-action films gradually merged with characters, firstly by multiplying them for group scenes, such as in *Titanic* (Cameron 1997). For individual characters, digital costumes were first visible, for example, in *Stuart Little 2* (Minkoff 2002), which combined live actors with a computer-animated mouse wearing the costume, or *Spiderwick Chronicles* (Waters 2008), with small computer-animated creatures interacting with actors in live-action scenes. Digital characters and costumes are clearly visible in *The Hobbit: An Unexpected Journey* (Jackson 2012), where digital doubles of characters and their costumes were created. Digital costumes are more evident in computer animation and gaming media with their completely computer-generated productions.

In digital media scholarship and practice, there is a growing interest in raising awareness of costumes as part of digital character development for game characters (Appleoff Lyons 2020; Salomaa 2018; Makryniotis 2018) and computer-animated characters (Kalmakurki 2021, 2024; Kalmakurki and Healy 2022, Boumaron 2018). In many contemporary CG live-action films, where all aspects of the actors' costumes are built digitally, there has been an expanding need for costume designers to shift their design development from physical actors to digital characters. In addition, there is a push to expand digitalism in live-action films from a sustainability point of view, as

big-budget Hollywood film productions have vast carbon footprints (Whittington 2022).[1] Making costumes digitally helps to decrease production costs and fabric waste. Fitting and testing processes via digital garment-making software cuts unnecessary, environmentally heavy material sampling processes. Despite its strong potential for eco-friendly productions and the ever-growing use of digital characters in live-action CG films, little is known about the design process of digital costumes and their relation to the overall worldbuilding in films. It is, therefore, important to deepen understanding of the designer's skill requirements and the opportunities and challenges posed by digitally generated costumes, in addition to a critical theoretical examination of these areas.

To discuss the aforementioned areas, this article focuses on costume design in CG live-action films and studies Deborah Scott's costume design process in *Avatar* (2009) and its sequel, *Avatar: The Way of Water* (2022), both directed by James Cameron. The data consists of a semi-structured interview with Deborah Scott regarding her costume design process on *Avatar* and specifically *Avatar: The Way of Water* and her collaboration with the director, the costume makers at Wētā Workshop and the digital costume artists at Wētā FX and Wētā Digital. Semi-structured interviews were suitable for this study as they enabled the definition of predetermined questions, some open-ended. In addition, this method permits changing the order of the questions depending on the interviewee's responses (Given 2012), which proved useful in the interview with Scott. A preliminary meeting with Scott to define interview questions enabled a more casual discussion about her work process and helped to create a more relaxed environment in the official interview. Additional interview questions were sent to Wētā FX digital artist Marco Revelant. There were specific and open-ended questions designed to shed light on the details of digital costume creation and the collaboration with the costume designer from the point of view of the digital professional. The transcribed interview with Scott was analysed using content analysis, focusing on themes regarding the costume design process, physical material engagement, and digital costume production. The analysis highlighted the intricate nature of the costume design process, which

[1] According to Whittington (2022), "Blockbuster films with budgets of over $70 million produce an average of 2,840 tons of CO_2 per production."

juggled between the art department, fabric manufacturing, digital character production, and performance capture filming. Visual and comparative analysis of the extensive visual materials was especially helpful in the analysis. The visualisation of the costume design process, from initial design ideas to digitally created costumes, was discussed in Scott's oral testimonies. The visual materials were Scott's costume renderings, photographs from physical fabrications made by Wētā Workshop during the costume development process, demo filming from motion tests of physical fabrication, photographs of digital garment making at Wētā FX, and analysis of specific scenes from the films.

As a theoretical grounding for this article, I build on film scholar Stephen Prince's (1996) concept of *perceptual realism* in digital cinema. Prince argues that realism in film is "rooted in the view that photographic images … are indexical signs" and, because "cinema is a photographic medium, theorists of cinema developed concepts of realism in connection with the indexical status of the photographic sign" (1996, 28). In CG films, there is a tendency to refer to *photorealism*, a concept that aims to achieve the same level of realistic detail as photographs. Even as cinema shifts from traditional photographic methods to the digital crafting of virtual worlds, it still upholds a photographic legacy (Crippen 2019). Even so, "realism is a descriptive category that can be applied to categories of cinematic image that traditionally have not been considered as realistic" (Prince 2012, 150), suggesting that digital films can depict imagery that appears truthful, even if it would be considered unrealistic in real life. Prince notes that the implementation of CG in films yields convincingly realistic photographic depictions due to the complex networks of perceptual correspondences woven into the films: "These correspondences which anchor with the physical space and living systems in daily life" show perceptual cues about surface texture, colours, motion, which can be identified as perceptually realistic (Prince 1996, 33). This article builds on this argument by examining how the *Avatar* films build perceptually realistic costumes on the digital characters. I explore how the filmmakers, more specifically costume designer Deborah Scott, the costume department of the Wētā Workshop and the technical team at Wētā FX, develop perceptually realistic costumes, discuss what key elements are part of the process, and the relationship between the real and the digital.

The *Avatar* films suit this study given that they feature digitally realistic costumes created by merging high-end CG film technology and embedding highly developed performance capture technology. *Avatar* represented a continuation of director James Cameron's interest and investment in merging digital technology with filming. Prior to making *Avatar*, Cameron tested the combination of computer-animated effects with live actors and environments in the making of *The Abyss* (1989) and *Titanic* (1997). *The Abyss* included the first three-dimensional CG character interacting with live actors. *Titanic* successfully embedded motion capture technology, especially in the most dangerous crowd scenes, replacing the "extras" used to illustrate large groups of people in films. Mocap filming provided realistic human behaviour that could be seamlessly used in digital character behaviour, making films with special effects more cost-effective (Sito 2013, 170, 210). For *Avatar*, Cameron built specific camera technology that seamlessly merges the filmed motion capture image with the pre-designed CG film. *Avatar* is an example of a film with an extensive production budget. According to movie budget and financial performance site *The Numbers*, the film had a $237-million production budget, which enabled the high standards of technology and extremely detailed post-production necessary to depict perceptually realistic worlds. *Avatar* grossed $2.9 billion at the box office. *The Way of Water*'s production budget was reported to be $350 million (Mendez 2022).

The narrative of *Avatar* is set in the year 2154 and tells the story of a human character, Jake Sully, who becomes a Na'vi humanoid, living on an Earth-like moon called Pandora in a distant planetary system. Sully joins the Omatikayan Na'vi clan living in the forests of Pandora and falls in love with Neytiri, another member of the clan. The first film introduces the Na'vi ways of life and their contrast with those of some of the humans, whom they call Sky People, leading to fierce battles towards the end of the film. *Avatar: The Way of Water* begins by illustrating Jake Sully's and Neytiri's family life, which is interrupted again by the Sky People. They flee to the distant atolls of Pandora and seek sanctuary with the Metkayina Na'vi clan in the aftermath of the attack by the Sky People. *The Way of Water* explores the journeys of the two Na'vi clans while adapting to each clan's ways and unified battles against the Sky People. The themes explored in this article address how costume design is reflected in the characters' specific living environments and personal identities

during their journeys in the overall story arc. I will do so by first addressing the costume design development and, specifically, the strong connection with the hands-on fabrication of physical materials before their digital creation. This will be followed by motion study as part of costume design development and the technical aspects of costume creation. This article finishes with remarks regarding the possibilities of digital costumes.

Material-led costume design development process

Digital media productions such as computer animation and gaming employ physical material examination as part of the costume design and digital creation process (Kalmakurki 2021, Kalmakurki and Healy 2022; Salomaa 2018). All physical materials have their own distinct characteristics and can be examined from the point of view of texture and material behaviour. These two important features of physical materials connect with perception through vision. As Tim Ingold attests, each physical material has its own distinct textural characteristics, and vision is important in understanding the texture. "Texture tells not of the form of things, but of their substantive composition" (2017, 102). In the moving image, material behaviour is linked with texture, as each clothing material has its own distinct way of behaving, falling and draping around the body. Prince adds that audiences rely on personal cues and perceptions when assessing individuals in real-life scenarios and characters portrayed in digital media (1996, 31). This resonates with Ingold's argument concerning physical material characteristics and how they are perceived by the audience. Costume design is closely related to textures, both digital and physical, as texture tells characters' stories and connects with a film's visual worlds. As is evident from the recent writing on costume design scholarship, texture and materiality more broadly play pivotal roles, not only in the way costumes look but also in the creative process of costume designers and the way they communicate with their colleagues (e.g., Pantouvaki, Fossheim and Suurla 2021; Dean 2021)

The reproduction of costume texture in its digital form and behaviour is guided by physical examination of the material and, specifically, tactile and embodied experience through touch (Kalmakurki 2021). The design process of the *Avatar* films shows this practice

applied to CG films. Early on in the making of *Avatar*, Cameron realised that, even though he was directing a digital film, there was a strong need for a hands-on and realistic approach to costumes. Cameron remarked that "you cannot go straight from imagination to CG; it won't look real" (2009). This resonates with Walt Disney's famous quote from the early years of animation: "I definitely feel that we cannot do the fantastic things based on the real, unless we first know the real" (Thomas and Johnston 1995, 71). Hence, the definition of "real" Cameron and Disney refer to means how any reproduction, hand-drawn or digital, should first be based on the world surrounding us. On this point, *Avatar* films' producer Jon Landau notes that in order to ensure that Wētā FX could produce digital costumes with photorealistic appearance and authentic movement, it was essential to provide them with a tangible reference point (Bennett 2022, 28). In order to create realistic costumes digitally, the makers at Wētā Workshop developed different kinds of methods for weaving, knitting and crocheting materials, representing the Na'vi way of making clothes, and this continued in the sequel. The hands-on approach was closely connected to the costume design development for digital characters and follows Walt Disney's and James Cameron's aim of "knowing the real" before going to the reproduction.

The hands-on experimentation was also used for costume design development, which has been shown to be an important part of finding inspiration for costumes in CG films. As a grounding for the hands-on experiments in *Avatar*, the makers at Wētā Workshop, along with costume designer John Harding, Mayes C. Rubeo, and Deborah Scott, studied several African, Mexican, Meso-American and Indonesian tribes, as well as Māori indigenous people's culture, ways of life and textile production. The aim was to understand the characteristics and philosophies of these cultures in order to create Na'vi culture and garment-making practices (Scott 2024; Harding and Rubeo 2009). In both films, ideas for costume materials stemmed from the characters' living environments. In *Avatar*, the materials were mostly linked with the forests of Pandora, such as flax, leather, and leaves, whereas in the sequel, the reefs of Pandora were introduced with new material varieties, such as seaweed or seashells. While working on *The Way of Water*'s production in New Zealand, Scott found a piece of native New Zealand Pāua shell on the beach (Scott 2024). Scott brought the shell to Wētā Workshop, and its colours were used as an inspiration

Fig. 1. Scott found a piece of Pāua seashell on the coastline of New Zealand. This was inspirational for one of Ronal's tops in AVATAR: THE WAY OF WATER

for the Metkayina reef clan's costumes. In addition, the distinct form of the shell was used as an inspirational guide for one of Ronal's tops (Fig. 1). This top design is an example of design development related to mostly hands-on experiments.

The character Ronal is tsahìk, the shaman of the Metkayina reef clan. Her distinct costume colouring matches that of the reef clan; however, it also includes colour shades specifically chosen for her and her partner Tonowari, the leader of the clan. The reef clan's environment and Na'vi bodies differ from the Omatikayan Na'vi clan from the forest of Pandora, who were introduced in the first film. The colour schemes of the reef clan's environment differentiate the two clans from each other, and costumes employed distinctive colour

forms, such as different hues of turquoise greens and warm browns and oranges in Metkayina clan costumes. In Ronal's introductory scene, when she meets one of the lead characters, Jake Sully, and his family from the Omatikayan clan, Ronal is presented in a strong orange beaded skirt and a top decorated with shells (see Fig. 2). The costume ensemble visually represents her strong personality and high status within the clan (Bennet 2022, 58). The colour coordination is linked with the principles of costume design for digital media, where a certain colour palette aids in maintaining the character's recognisability across different scenes, enabling the audience to easily grasp the details of the costume as the scenes progress (Bui et al. 2022, 146). As the clans employ their own colour scheme, costume design was a strong visual signifier for representing the clans, the characters' personal journeys, and narrative changes.[2]

A visual analysis of the hands-on experiment images provided by Scott illustrates the role of material examination as part of digital costume creation for Ronal's costumes, shifting through several iterations during the material experimentation. Costume drawings were used as a starting point for the designs, thus "the 2D designs would change significantly between the design on paper to the actual manufactured piece" (Scott 2024). Tactile reference materials, such as the aforementioned Pāua shell, are employed as inspiration and guidance for three-dimensional form in the hand fabrication process. To continue on Ronal's top's design development in her introductory scene, visual analysis of the many original costume drawings illustrates that it was initially designed as a neck piece with two hanging braids (see Fig. 3) and altered later to cover her bust area (see Fig. 2). Therefore, the design idea in the costume drawings was used as a guide for the fabrication of the costume by hand. Comparing the early design sketch in Fig 3. and the final rendering in Fig 2. shows that the dark brown hanging braids have been omitted from the design, and the neck piece has been extended to cover the bust area. The hands-on experiment stage led the design in another direction by removing the braids and making the top resemble a woven neck piece. During the hands-on experiment, they carved the shells by hand and placed them individually on the woven neck piece (Bennet 2023, 58).

[2] Scott (2024) notes that Sully's children from the Omatikayan clan adapted to the new living environment more quickly than the adults, and the children's costume colouring gradually changed scene by scene to correspond more closely to the Metkayina clan's costumes.

Fig. 2: Finalised costume illustration of Ronal's costume ensemble for her introductory scene in the film AVATAR: THE WAY OF WATER *© 2022 20th Century Studios, Inc. All rights reserved.* JAMES CAMERON'S AVATAR *is a trademark of 20th Century Studios.*

Fig. 3. One of the early design ideas for the Metkayina reef clan visualises Ronal's top design as much shorter than what is visible in the film. The image shows the clan's distinct costume colouring. © 2022 20th Century Studios, Inc. All rights reserved. JAMES CAMERON'S AVATAR *is a trademark of 20th Century Studios.*

Another method of hand fabrication was 3D printing and painting some of the shells in the physical costumes (Scott 2024). The design development via manual fabrication, testing, and modification resonates with Pantouvaki, Fossheim and Suurla's suggestion that "costume is not merely a passive artefact, or a project created from idea to material … but an enactment between makers and materials" (2021, 203). The process of making the costume, from Scott's initial design idea to the physical piece, played a highly important role in costume development, generating new ideas to refine the design through the hands of the makers and via the guidance of the designer. The evolution of the design to cover the bust was finalised during the digital production of the neck piece, which will be discussed in the latter part of this article.

Digital costumes in motion

In order to produce perceptually realistic movement for costumes, the hands-on fabrication process also included motion testing before the garments' digital reproduction. All materials have their own physical

characteristics: how they sit, move, and drape on and around the body. Reproducing these elements seems to require an examination of motion with hand-drawn or digital methods, such as traditional and computer animation. For example, as early as the production of *Snow White and the Seven Dwarfs* (1937), Walt Disney animators studied real-life fabric behaviour by perception through vision by moving pieces of different quality fabrics in the air or studying garments on a moving person (*Snow White and the Seven Dwarfs* 2002). Even though the medium has changed from hand-drawn animation to digital, this practice is continued by the recent Walt Disney animators studying how fabrics fold and behave. In the production of *Frozen 2*, Technical Animation Supervisor David Suroviec explains that they "study things like wrinkle quality, the speed of the ripples travelling through and individual shapes" (*Into the Unknown: The Making of Frozen 2*). This visual data is used to create realistic material movement against the character movement in scenes. Hence, Prince (1999; 2012) has referred to the fact that it is exactly motion that makes digital films realistic, which corresponds to the film production's aim to study real-life movement for digital reproduction. I argue that motion study is an embodied practice, as studying a physical costume during character and costume design development enables the designers to understand on a somatic level how the materials and weight or pressure of the garment feel inside the body, which is essential not only for garment observation through vision but also for envisioning alteration ideas for the costume (Kalmakurki 2021).

The Way of Water production underwent a very special motion testing process connected with water. In underwater testing, simple pieces of costumes, not the actual hand-fabricated garments, were tested in a water tank in motion and filmed for use as a guide in their digital reproduction (Scott 2024). The film includes several underwater scenes that were filmed using underwater motion capture. The underwater motion tests were informative in two ways. First, for costume design development, to show if the materials moved in the desired way underwater. Second, the filmed motion test footage was essential for the team at Wētā FX, who reproduced the costumes digitally. Scott explained that during water testing, the functionality of the costume can be examined, as then "you get to see them kind of come alive" (2024). The testing provided the possibility of altering the materials, beading, or adjusting other decorative elements for the preferred costume outcome, such as adding or reducing weight in

a garment. The team was able to see the flow of different materials and behaviour underwater, which is different from motion against the air. The underwater testing was executed to achieve a "costume's maximum potential" (Scott 2024).

The filmed motion test data was studied by Wētā FX regarding the behaviour of the fabric in movement to fine-tune the garment simulation settings to match such behaviour. A physical motion model provides a verified reference point to consult and helps eliminate a lot of guesswork from the process (Revelant 2024). Altogether, these motion tests reveal the tactile experience of the materials underwater, how they move against the body and in motion, and allow these important elements of the costume to be realistically reproduced digitally. The filmed footage allows costume modification during the hands-on experiment stage, but refinements can also be made in the digital reproduction.

Another major part of *Avatar* films' productions for producing convincing motion was the motion capture filming. This filming was the actual film shoot, not pre-production, when costumes were still in development. However, motion capture affects the costume design process as it is executed before the body forms of the digital characters are designed. Therefore, filming begins before the costume designs are finalised (Scott 2024). This production issue was resolved in the *Avatar* films by designing a standard garment, such as a plain loincloth, and using it as a template for all subsequent loincloth varieties. The standard garment became a placeholder for motion capture and enabled the team to continue designing the costumes in parallel with motion capture filming (Scott 2024). However, some of the costumes required more work time in the digital production to match the character movement filmed in motion capture (Revelant 2024). Due to the complexity of the motion capture production process in both *Avatar* films, it is only mentioned briefly in this article. Motion capture was important for producing truthful character movement and motion study contributed to producing perceptually realistic costumes.

Digital costume development

Year after year, digital productions are becoming more ambitious in their attempts to represent realism in film. This is achieved by developing in-house software for easier workflows and the realistic

representation of human, cloth, and hair movement. In 2009, *Avatar* was the result of fifteen years of "film development and innovative cinematic technology" (Bennett 2022, 17) and with *The Way of Water*, the production pushed the technology and visual concepts further. One of these advances was the Anatomically Plausible Facial System (APFS), which Wētā FX developed to copy the behaviour of facial muscles closely and to use the data in the Na'vi character's facial features. The actors and their digital characters share the same encoded data and the result allows each nuance of the actor's performance to be captured in the digitally created film. Another goal in the sequel was to expand the facial system to complete body forms. The primary aim was to enhance the production pipeline to efficiently handle character work in a reduced timeframe (Sprenger et al. 2023). Wētā FX also used their in-house simulation framework *Loki* as a plugin for Autodesk Maya software to control hair, cloth, and water in the same blended environment (Letteri 2023; Zhai et al. 2023). The garments' underwater motion testing is connected with *Loki* to provide a realistic representation of fabric movement in a water environment. Advancements in motion capture technology contributed to digitally replicating realistic movement, enhancing the overall realism of the film.

Photoscanning garments is another common practice that achieves a realistic representation of clothing in computer-animated productions, gaming, and CG films. It speeds up the digital garment creation process as artists are not required to start costume creation from nothing. Another common way to produce realistic costumes is to employ the 3D clothing simulation software Marvelous Designer. Wētā Digital artist Marco Revelant (2024) attests that they employed both photoscanning with Reality Capture software and Marvelous Designer software in the creation of the digital costumes in the making of *The Way of Water*. Revelant explains that Marvelous Designer has been part of Wētā Digital's workflow since the production of *The Hobbit: An Unexpected Journey*. In *The Hobbit*, Wētā generated digital replicas of characters, which substituted real actors in instances where using a live person would pose too great a risk in filming. The garment patterns of the costumes worn during live-action filming were used as templates for making the digital cloth patterns. Subsequently, they crafted precise digital replicas of the characters by making digital double costumes and photoscanning the actors (Moore 2013).

Costumes made by Marvelous Designer helped to make the digital doubles appear more realistic.

To return to Ronal's top in her introductory scene and explain the development of the costume as a finalised digital (and perceptually realistic) piece, a costume drawing and the hand-fabricated neck piece were given to the Wētā FX team, who digitally built the costume. The neck piece was photoscanned first to evaluate its look and build (Revelant 2024), meaning a closer examination of the garment's three-dimensional form. In this phase, the photoscanned garment is placed onto the Na'vi avatar body. However, the photoscanned garment was originally fabricated for a human body size, and the Na'vi characters are much taller and have slightly different body proportions than humans. Hence, the photoscanned garments required re-scaling onto a new body type. In the case of the neck piece, this required enlarging the circumference, as the Metkayina clan bodies have broader neck and shoulder areas than humans. The hand-fabricated garment assists the digital execution by providing insight into the garment's texture and how it was created via stitching. In addition, the physical piece is informative in showing how complex patterns have been used to make the costume (Revelant 2024).

The digital production stage shows that building digitally realistic costumes requires multisensorial examination through vision and touch. As Prince (1998) argues, audiences rely on a shared reservoir of familiar objects and cues when assessing individuals in reality and as depicted characters in digital media. Even though photoscanning helps to build the three-dimensional form, the material texture makes the garment recognisable. In-house software development assists in the making of these digitally realistic textures. Wētā FX modified Maya software to produce fur and everything that illustrates similar shapes and textures, such as tassels. A series of proprietary tools were used to digitally create these details in the costumes. Apteryx was one such tool used to create different kinds of detailed feathers and Weaver was used to create weaving patterns (Revelant 2024).

A comparative visual analysis between the digital execution of Ronal's neck piece and the more finalised digital character attire shows that costume design development continued in the digital environment. Ronal's top in the film illustrates that the swirling weaving from the original design idea in the neck piece is expanded across the chest and finished with woven straps, including shells

hanging at the tips of the straps. Scott (2024) remarks that this type of costume development included multiple virtual fitting meetings with Wētā Digital. Virtual fittings resemble a typical costume fitting process in a physical space, which is a stage in costume production where the costume designer can see the costume on an actor's body, discuss the feel of the garment and even adjust the costume's design and details. These might be related to colour, fit, structure and texture. In addition, it is important to study movement in the virtual fitting process. Such an aspect is natural in live-action filming; however, it has to be digitally recreated in the virtual fitting room (Scott 2024). On the virtual fitting stage, the digital costume is still a work in progress (Scott 2024). In the digital realm, the conversation is held between the costume designer and digital artists, not between actors or makers of physical costumes. The common interaction between the designer and actor is absent in digital costume development and is replaced by a discussion related to the visual appearance of the costume rather than the costume's embodied experience conveyed by the actor.

As a result of the virtual fitting sessions, Ronal's neck piece developed into a top, as seen in her introduction scene in *Avatar: The Way of Water*. The top also includes a separate necklace that hangs from her neck, made with pink and blue seashells. The necklace is an important addition to her costume as it links her character with her position as the tsahìk of the Metkayina clan. In the previous film, a similar necklace was seen on Mo'at, who was the tsahìk of the Omatikayan forest clan. This necklace serves as a visual link between the spiritual leaders of both clans. The finalised digital costume textures were accomplished by mimicking colour information from polarised photos taken of the fabricated garment at the Wētā FX studio and comparing the photographs with the hand-fabricated costume side-by-side with the physical hand-fabricated piece (Revelant 2024).

Digitally and perceptually realistic costumes

As the examples in this article show, digital costume development is mostly a process[3] which involves both the exploration of physical and digital materials. The collaborative efforts between costume designer

[3]The production of *Avatar: the Way of Water* also shows that the design process of digital costumes requires considering performance capture filming, which complicates the design process presented in this article.

Scott and the makers at Wētā Workshop highlight the intricate process of creating realistic digital costumes. By exploring various methods of textile production and drawing inspiration from real-world examples and cultures, they crafted garments that authentically represented the Na'vi way of life. This hands-on approach, grounded in extensive research, and the choice of materials not only informed the design of the hand-fabricated costumes but also influenced the development of the digital characters' attire and reflected the characters' natural environments. Overall, this meticulous attention to detail and cultural context contributed to the immersive world-building of both films. The design ideas were led by material textural forms, as suggested by Ingold (2013), by a hands-on approach exploring the tactile feel of the materials (Pantouvaki, Fossheim, and Suurla 2021), and further developed as digital costumes and materials by reproducing physical material behaviour as digitally realistic. The digital costume design process shown in this article points out the main characteristics of the costume designer's skill requirements when working on CG live-action films. This requires recognising the significance of transferring ideas from hands-on experimentation to the digital realm and pushing design ideas further in the digital environment.

In ever-evolving and challenging digital film productions, advances in technology continuously push the boundaries of realism. The innovative development of software for *Avatar* and its sequel demonstrated a commitment to achieving unparalleled authenticity between the real and digital. The worldbuilding of both films includes scenes with unrealistic outcomes. However, they seem real to the audience. For instance, the Hallelujah Mountains of Pandora feel believable despite the fact that such mountains float in mid-air and defy the laws of the real world. Prince argues that such images point to the existence of the object and "they indicate their existence in terms that would be indexical" (2012, 150) even though we know such things are not real. Equally, costumes in the *Avatar* films support imaginative worldbuilding by blending with the colours and textures of each clan's living environment. Real-world references were developed to match the world of Pandora, by changing fabric movement and texture or by combining these areas. The physicality of materials can be changed to match Pandora, as Scott points out: "by the time you got to make something, it might be stiffer than you would want it to be represented in the virtual world" then you say "it looks like this, but it moves like that" (2012, 150).

The hand-fabricated pieces served as essential guides for digital construction, facilitating a deeper understanding of texture and garment construction techniques. Combining visual and tactile examination, this multisensory approach transfers the important multisensorial effects of costumes in their digital form. I argue that the extensive process of physical material examination, hand fabrication, motion testing, digital creation and virtual fittings all contribute to Prince's concept of perceptual realism. Prince (1996) attests that it is important to digitally replicate perceptual cues related to surface texture, reflectance, colouration, motion and distance. These aspects provide a set of cues that align with the characteristics of physical space and natural systems in everyday life, enhancing the credibility of digital imagery. This article shows the process by which costumes in the *Avatar* films were built as digitally realistic, contributing to the important outcome of having audiences believe in that realism. Ultimately, this collaborative effort between physical costume artisans and digital experts underscores the importance of both traditional craftsmanship and technological innovation in creating digitally realistic costumes for immersive cinematic experiences.

Incorporating photorealistic imagery in the worldbuilding of CG films helps viewers connect these images with their own personal perception, even if the digital image is slightly altered and does not fully adhere to their experience. Addressing some realistic points of reference allows for creative departures or stylish deviations from those references (Prince 1996, 36). Even though the examples in this article showed the reproduction and comparison of objects and textures from real life, the digital medium is a creative playground with numerous opportunities that cannot be implemented in live-action films or in live performances. In Deborah Scott's terms, the costumes were adjusted from real life into a different reality, that of the world of Pandora. In the digital medium, costume designers can take inspiration from any physical reference material and combine different characteristics of real life in digital costume, such as texture, material weight, depth, colour, and so on (Scott 2024; Kalmakurki 2021). In *The Way of Water*, the costumes did not depict materials from Earth but from the imaginative world of Pandora, including new types of colour and texture combinations, as well as material behaviour choices (Scott 2024).

Creativity in CG films is equally evident in the design of the digital characters, whose bodies can be quite different from those

of a human. The blue-skinned Na'vi characters were three metres tall, had tails and varied body proportions, and the costumes were re-scaled to their unusual bodies. These bodily features provided new opportunities for the costume designers to approach costumes from outside the framework of the natural human body, how costumes are structured and how they sit on these new types of bodies.[4] As Pantouvaki, Fossheim and Suurla attest, "costume is never free of meaning; it is sensitised towards meaning creation in relation to the human body – even in abstract representations of it, or even more when the body is not physically present but implied" (2021, 200). This article broadens this argument by showing how digitally realistic costumes are also included with significant denotations, even though they are not presented on a physical body or viewed by the audience as physically manufactured. The digital medium offers ways to use the costume in an imaginative way. The examples in this article did not show imaginative performative elements of costumes, such as defying gravity or material function in an unordinary way, meaning that digital costumes also offer further creative potential to expand and support digital realism. The digital costume-making process increases the number of professionals involved in the costume-manufacturing process. Designers, craftspeople, and digital artists are involved in digital costume development. The makers of physical costumes extend into the work of digital costumes and vice versa. In CG filming, costume design is an intricate and creative process which adjusts realism to a different reality, that of a digital world. ■■■

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[4]Equally, computer-animated feature films offer a space for costume designers to develop costumes for non-human body shapes. For example, in the production of *Puss in Boots* (Miller, 2011), Isis Mussenden worked closely with character artists to develop the body shape and costumes of Humpty Dumpty, an egg-shaped character.

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