Virtual Archaeology Review, **16**(32): 71-84, 2025
https://doi.org/10.4995/var.2024.22584

Received: October 8, 2024
Accepted: December 24, 2024

"*I FREGI DEL CEPPO*": WHEN ARTIFICIAL INTELLIGENCE AND GEOMATICS MEET IN THEATRE

"I FREGI DEL CEPPO": CUANDO LA INTELIGENCIA ARTIFICIAL Y LA GEOMÁTICA SE ENCUENTRAN EN EL TEATRO

Pietro Bartolini[a], Alessandro Conti[b,*], Lidia Fiorini[b,c], Grazia Tucci[b]

[a] Accademia teatrale di Firenze Centro Culturale di Teatro APS, via della Pergola, 36 – 50121 Firenze, Italy.
direzione@accademia-teatrale.it

[b] GeCO Lab, Dept. of Civil and Environmental Engineering, University of Florence, Via di S. Marta, 3 - 50139 Firenze, Italy.
alessandro.conti@unifi.it; lidia.fiorini@unifi.it; grazia.tucci@unifi.it

[c] Sapienza University of Rome, Piazzale Aldo Moro, 5, 00185 Roma, Italy

Highlights:

- The reuse of 3D reality-based digital data in theatre productions supports the cross-valorisation of cultural activities.
- The frieze of the Ospedale del Ceppo: from digital documentation for preservation to scenic design and performance.
- The integration of digital technologies, avatars and artificial intelligence in contemporary theatre scenography.

Abstract:

The integration of three-dimensional (3D) digital technologies into cultural heritage and theatre is transforming how historical works are preserved and experienced. This paper focuses on the performance *I Fregi del Ceppo*, which exemplifies this trend by using 3D data to bring the Renaissance friezes of the Ospedale del Ceppo in Pistoia, Italy, to life. Originally digitised for conservation, the friezes served as the foundation for a theatrical production. The project used artificial intelligence (AI) tools to analyse and animate the frieze characters' postures and relationships. The performance incorporated a 180º multi-projection system that synchronised human actors with digital projections, merging live performance with digital heritage. This work highlights the broader trend of integrating AI and digital tools into theatre. Body scans, motion tracking, and emotion recognition enable new storytelling methods, while virtual characters and avatars allow performers to explore identity and interaction in novel ways. The fusion of AI with performance art is pushing the boundaries of creativity, generating dialogues, analysing performances, and enabling real-time interaction with human actors. *I Fregi del Ceppo* demonstrates how digital heritage can enhance theatre, extending the life of historical works and offering new cultural experiences. It also points to a future where AI and 3D technologies will play an increasingly central role in shaping the performing arts.

Keywords: 3D models; heritage data re-use; theatre; digital scenic design; conservation

Resumen:

La integración de tecnologías digitales tridimensionales (3D) en el patrimonio cultural y el teatro está transformando la forma en que se preservan y experimentan las obras históricas. Este artículo se centra en la representación *I Fregi del Ceppo*, que ejemplifica esta tendencia al utilizar datos en 3D para dar vida a los frisos renacentistas del Ospedale del Ceppo en Pistoia, Italia. Originalmente digitalizados para su conservación, los frisos sirvieron como base para una producción teatral. El proyecto utilizó herramientas de inteligencia artificial (IA) para analizar y animar las posturas y relaciones de los personajes de los frisos. La representación incorporó un sistema de multiproyección de 180º que sincronizaba a los actores humanos con las proyecciones digitales, fusionando la actuación en vivo con el patrimonio digital. Este trabajo destaca la tendencia más amplia de integrar la IA y las herramientas digitales en el teatro. Los escaneados corporales, el seguimiento de movimientos y el reconocimiento de emociones permiten nuevos métodos de narración, mientras que los personajes virtuales y avatares permiten a los actores explorar la identidad y la interacción de maneras novedosas. La fusión de la IA con el arte escénico está ampliando los límites de la creatividad, generando diálogos, analizando actuaciones y permitiendo la interacción en tiempo real con actores humanos. *I Fregi del Ceppo* demuestra cómo el patrimonio digital puede enriquecer el teatro, extendiendo la vida de obras históricas y ofreciendo nuevas experiencias culturales. También señala un futuro en el que la IA y las tecnologías 3D jugarán un papel cada vez más central en la configuración de las artes escénicas.

Palabras clave: modelos 3D; reutilización de datos patrimoniales; teatro; diseño teatral digital; conservación

* Corresponding author: Alessandro Conti, alessandro.conti@unifi.it

1. Introduction

The 2014 European Council Conclusions on Cultural Heritage (Council Conclusions, 2014) and the subsequent European Commission Recommendation on a Common Space for Cultural Heritage 2021 (Commission Recommendation, 2021) added digital resources to tangible and intangible cultural heritage, highlighting how they represent a cultural, environmental, social and economic resource and a fundamental means of disseminating knowledge.

Digital resources, intended not as mere replicas of physical artefacts but as highly informational digital assets, create true digital ecosystems: environments where resources interact with each other and with people, authors, users, producers, etc.

The ability to access, associate and reuse digital resources according to personal criteria and originality generates new relationships, exchanges and, above all, new cultural content. The relationship between cultural heritage and digital resources is therefore not one-sided: a single cultural heritage can be associated with several digital resources (Digital Library, 2023). Among these, the three-dimensional (3D) ones offer great possibilities of re-use, allow physical reproductions, allow the reconstruction of no more existing or disassembled works, and the possibility of being integrated, reshaped or modified in their appearance to allow new narratives.

This greatly expands the meaning of valorisation, which, according to articles 111-112 of the Italian Cultural Heritage Code (2004), also includes "educational purposes aimed at promoting and improving knowledge of the historical, artistic and architectural heritage".

Immersive experiences, gaming, etc. are among the most widely used digital storytelling tools (Bonacini, 2021), but this idea is not immediately associated with theatrical productions, although theatre has always been where stories are told and performed.

2. Aims and structure of the paper

Theatre, sculpture and digital documentation of the restoration of a work of art can be very different worlds, even though they belong to the common domain of cultural activities. This article presents a project that connects these domains, with the effect of amplifying the value of each activity and promoting it to a wider audience. The initial idea for this project came from the digital survey of the frieze of the Ospedale del Ceppo in Pistoia (Italy), a very important but little-known Renaissance work, carried out in 2013 to document the state of conservation and the restoration of the sculpture (Fig. 1). During the restoration work, a special scaffolding was erected to allow the public to appreciate the quality of the artwork. For the first time, visitors were able to admire the bas-relief up close, with very 3D and almost life-size figures.

Observed from this height, the 43 m long strip gave the impression of an immersive space and emphasised the stage-like nature of the scenes, populated by characters with pronounced individuality. The idea of a theatrical show to bring the stories on the friezes to life, building the scene and the action of the characters around the 3D digital data collected, came immediately to mind.

Figure 1: The loggia of the Ospedale del Ceppo in Pistoia.

The article presents the development of this project, framing it within the broader theme of the use of 3D acquisition and modelling technologies in the performing arts (Section 3). Section 4 offers a brief description of the artwork and its history, followed in Section 5 by the presentation of the acquisition and spatial data collected. Section 6 frames the work presented in the line of post-dramatic theatre, while Section 7 details the technologies available for contemporary theatre production. Section 8 introduces the use of avatars in theatre, while Section 9 shows how artificial intelligence (AI) tools can be applied to them. Section 10 illustrates how the *Accademia Teatrale di Firenze* has been producing performances for years that integrate 3D spatial data in various ways, with a particular focus on the show dedicated to the frieze of the Ospedale del Ceppo. Section 11 describes the creation of the script, which was developed from the analysis of 3D models using artificial intelligence and the technical realisation and implementation of the show. The article concludes with insights into future perspectives on the use of 3D spatial data in theatrical productions.

3. Digital technology and performative art

The etymology of the word “theatre” finds its origin in the ancient Greek noun *θέατρον* (théatron) composed of the verb root *θεάομαι* (theáomai), meaning “to look”, and the suffix *-τρον* (-tron), used to indicate a place. The theatre is then, in the truest sense of the word, “the place where people look”. The origins of Western theatre date back to ancient Greece, where dramatic performances were originally an integral part of religious rites in honour of the god Dionysus. In its long journey of transformation and adaptation, theatre has accumulated perhaps the richest historical and cultural heritage of all human arts and techniques. This is because it is configured as the alchemic place where all the arts meet and merge, producing that special propulsive *ἐνέργεια* (*energheia*, i.e. energy) that translates from one to the other in infinite dynamic metamorphoses of development and progression. The theatre and its constituent arts, such as Mnemosyne and her Muses, are both living archives and custodians of collective cultural memory, passing on the legacy of technical and hermeneutic skills for performative creations balanced between tradition and innovation, in order to perpetuate knowledge and culture.

From its beginnings, the theatre has been the place where technologies have been developed, at first rudimentary ones such as masks, revolving devices for changing scenes (called *periaktoi*), machines for simulating flight, hatches for apparitions, and later, over the centuries, more sophisticated systems. During the Renaissance, complex machines were developed to create special effects and stage illusions created with 3D cross sections and backdrops painted in “accelerated perspective”. In the 19th century, the invention of electric lighting and stage machinery radically changed the theatre, making it possible to produce increasingly elaborate performances (Nawata & Dethlefs, 2022). With the advent of the digital revolution, theatre has been further transformed by the integration of technologies such as video projection, computerised lighting, binaural digital sound effects, robotic movement and the integration of generative neural networks at all levels of production (Pizzo, Lombardo, & Damiano, 2019).

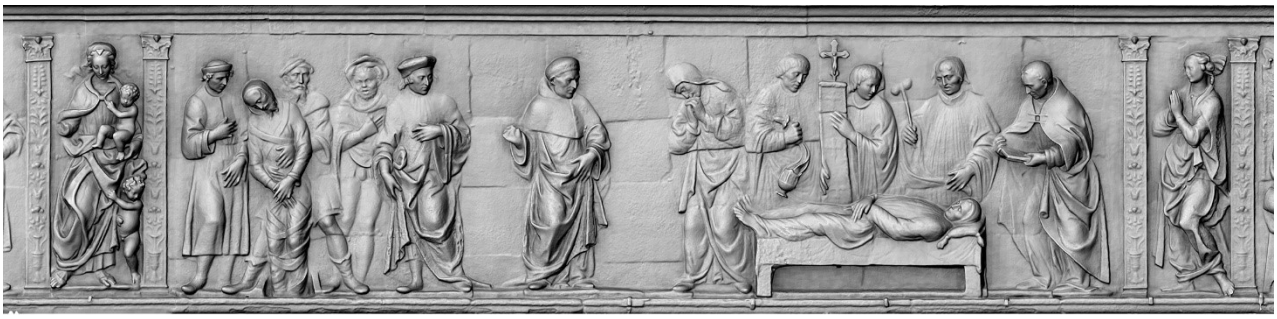
From conception to real-time interactive feedback with the audience, new fields of exploration have opened up, allowing artists to develop new forms of expression and create immersive experiences for the audience. From the very beginning, theatre, technology and science have fed off each other, so that each discovery in one field has always determined an innovative impulse and development in the others, choosing the stage as the ideal container for the integration of all the arts and sciences, an ecosystem in which humankind can find itself, maintain well-balanced relationships and live in harmony with nature.

4. The frieze of the Ospedale del Ceppo

The loggia of the Ospedale del Ceppo in Pistoia was built between 1512 and 1517 to upgrade the building of this ancient religious welfare organisation founded in 1277.Like the loggias designed by Brunelleschi and Michelozzo for the *Spedale degli Innocenti* and the *Ospedale di San Paolo* in Florence, this one is decorated with glazed terracotta, a typical Florentine Renaissance technique developed by Luca della Robbia in the first half of the 15th century (Henderson, 2006).

It differs from these models in that the decoration is not limited to the circular elements (called *tondi*) in the spandrels of the arches, but also occupies a strip approximately 1.50 m high and 43 m long on two sides, making this monument one of the largest and most important examples of this technique. Most of the large frieze is attributed to the artist Santi Buglioni. The iconographic programme of the frieze represents both the religious and civil importance of the hospital and is composed of seven sections, each about 5 m long, separated by allegorical representations of the cardinal virtues (Prudence, Faith, Charity, Hope and Justice). In each corner, there are cartouches with quotations from the Beatitudes and a Siren, which carries the hospital's coat of arms. The scenes represent the Seven Works of Mercy (Dressing the Undressed, Housing the Wayfarers, Consoling the Sick, Visiting the Prisoners, Burying the Dead, Feeding the Hungry, Giving Drink to the Thirsty) and relate each one to the charitable activities carried out by the hospital (Marquand, 1918 and 1919, Fig. 2).

In the centre of six scenes is Leonardo Buonafede, the *spedalingo* (person in charge), who commissioned the work. His successor Bartolomeo Montechiari is instead depicted in the last scene, modelled only at the end of the 16th century by Lorenzo Paladini. The work is characterised by an original mixture of subtle theological references and realistic details of daily life in a hospital, an institution that in the 15th century was also responsible for the reception and quarantine of pilgrims and travellers, the care of the poor, burials and other activities that could have exposed the city to epidemics.



(a)

(b)

Figure 2: 3D model (a) and orthophoto (b) of the *Burying the Dead* scene after the restoration.

5. The digitalisation

According to the principles of the Venice Charter, each phase of a restoration project must be carefully documented, from the preliminary study to the valorisation and dissemination (Quintero, Blake, & Eppich, 2007). This methodology was employed for the restoration of the hospital façade and the ceramic decorations. High-resolution 3D models and orthophotos were generated before and following the restoration.

These were utilized to create thematic maps delineating the components and materials utilised, the techniques employed, the kind and extent of deterioration, and the interventions conducted by the restorers. Now, in the new *Museum of the Spedale del Ceppo*, the same orthophotos and 3D digital models allow visitors to admire the scenes of the frieze up close, in full size, virtually and interactively. The survey was carried out in two phases. In the first, the entire façade was surveyed from the square using a terrestrial laser scanner. As the ceramic decorations are 9 m above the ground, the resulting point model did not have sufficient resolution to show the details clearly, and the colour quality was also inadequate. For this reason, once the above-mentioned customised scaffolding had been erected, a close-range photogrammetry campaign was carried out. High-resolution images made it possible to capture all the details of the high-relief figures at close range and from all angles. A separate Structure-from-Motion (SfM) photogrammetry project has been carried out for each of the sections. However, they are all referenced to the same reference system, as the coordinates of the control points are derived from the common point model generated from the scans.

The critical issues, design and implementation of the survey have been extensively discussed in previous papers (Tucci, Bonora, Conti & Fiorini, 2015 and 2017). Instead, it is worth emphasising here that the outputs of geomatics techniques include point clouds, mesh models and orthophotos. These digital products allow manipulating 3D objects, to enlarge or to observe them from unusual points of view, better than would be possible by observing the real object from the ground. This allows researchers to see barely visible details and relationships between parts, and to record diagnostic and interventional data on 3D maps. They can assign physical properties to models to simulate their response to external inputs, creating true "digital twins" (Marra, Gerbino, Greco, & Fabbrocino, 2021).

The same digital products form the basis to create 3D prints or virtual restorations, can be used for animation, morphing, video mapping and other communication and dissemination applications. This is not surprising given the predominant role of 3D modelling and animation in much of today's visual creative industries, particularly film and video games. The tools and techniques used in scientific and commercial applications are similar, but in cultural heritage applications, it is crucial that it is always possible to understand whether a 3D model is based on real data and geometries or has been modelled from scratch, and whether the reliability of the conjectures on which the reconstruction of supposed elements is based (London Charter, 2009; Denard, 2012). On these premises, forms of communication using 3D models are particularly effective, as they allow an immediate experience of objects that are not physically present or visible.

The present case shows how the 3D data of this artwork acted as a mediating element between different genres, facilitating the understanding of an original play inspired by a little-known sculptural work. As mentioned above, the relationship between a physical cultural object and its corresponding digital resource can be multifaceted: in this case, a tangible cultural object such as the frieze has given rise to several digital resources, including a theatre show that can be considered as a new intangible cultural resource.

6. Theatre for robots and robots for theatre: origins and development of the interactions between virtual humans, avatars and human performers

Artificial intelligence (AI), neuroscience and robotics studies can reproduce human intelligence and behaviour, and their integration into performative art deepens our understanding of our inner mechanisms and relationships with other animate and inanimate beings.

The premises of digital theatre can be traced back to the artistic, cultural and philosophical crises of the 19th and 20th centuries. Concepts such as Nietzsche's *Übermensch* and the histrionic actor sparked debates about individualism and ethics, with some seeing these ideas as necessary for human progress and other critics accusing them of promoting selfishness and social disintegration. If art aspires to be universal, and performative creation focuses on the reciprocity of relationships, the “Ego” must be subordinated to the collective, speaking to listening, and the “Other” must be prioritised over the “Self”. Against the histrionic self-referentialism of the 19th century, the voices of early 20th century artists called for a pure technique of interpretation.

Edward Gordon Craig (1907) theorised about the advent of the *Uber-marionette* to replace the actor, after Flaubert who stated that the artist should be invisible and omnipotent in his work. Eleonora Duse, the greatest actress of the time, condemned the “actor's theatre” and called for a total renaissance.

Robotics was born in the 1920s with Karel Čapek's play R.U.R. The foundations for the development of theatrical disciplines into computer sciences are laid for a necessary renewal of modern theatre. The processes of analysing human action are explored at ever deeper levels, from the masks of Greek tragedy to those of the comedians of art, to the theory of action, perceptual systems, linguistic and neural processes. This transformation has revolutionised every element of theatre, making the distinction between what is planned and what happens spontaneously on stage obsolete. The new concept of theatre, defined by Hans-Thies Lehmann (2006) as “post-dramatic”, is no longer limited to a “black box” or a “linguistic artefact”, but focuses on what the theatrical medium actually “does”. Through the distribution of organic and inorganic bodies in real space and time, contemporary theatre creates unique and unrepeatable experiences and sensations, always open to innovation and continuous experimentation, in line with the philosophical and artistic reflections that continue to inspire today's cultural debate.

In the context of the theory of post-dramatic theatre and the experimentation with new digital technologies applied to scenic art, the project of the performance "*I Fregi del*

Ceppo": a representation entirely derived from the digital analysis of the 3D models of the seven parts of the frieze on the façade of the Ospedale del Ceppo in Pistoia, was staged by the company of the Accademia Teatrale di Firenze, directed by Pietro Bartolini.

Each frieze depicts a dramatic scene in high relief, populated by almost life-size and strongly characterised figures, with planes of action and relationships clearly indicated by the postures and orientations of bodies and faces. Each scene is a complete narrative, presenting multiple simultaneous levels of action and a particularly complex dramatic situation, which was decoded and interpreted using a Generative Adversarial Network (GAN) algorithm for storyboarding and script composition. Emotion Recognition (ER) technologies were also used to create a coherent cinematic language, realised with virtual cameras on the 3D models and a dramatisation performed by real human actors, synchronised with their digital doubles of the frieze characters. A performance in which cinema, theatre, dramaturgy, sculpture, acting, stage action, animation and 3D graphics give life and voice to the sculptures of the friezes, combining different media while respecting the traditional Aristotelian rules of dramatic unity.

7. The integration of digital technologies in contemporary theatre scenography

Stage composition is an operation of systems that are interconnected in various ways that define styles of representation. The main systems, which include all others, are scenic design, sound, lighting, and performers. The realisation of the scene is the result of trans-systemic operation, the proportioning, integration and fusion of different systems. The set design adopted advanced virtual scenery technologies in its various implementations, like augmented reality (AR), virtual reality (VR), mixed reality (MR), extended reality (XR). Sound is the subject of research that explores the infinite possibilities of binaural systems, which can create a sense of spatiality comparable to that of sight, thus giving sound artists and engineers previously unimaginable possibilities of representation. Computer-controlled lighting systems, such as the use of light-emitting diode (LED) and laser technology, motorised video projectors, video walls that integrate video into the set design, are one of the main areas of interest for digital artists today. Finally, the human being, a universe still unknown, is explored employing intermediate models and tools: in the past with automata, today with avatars and robots. The skills needed to manage the hyper-technological system represented by digital theatre are supported by the latest generations of exponentially growing generative AI, capable of assisting the artist from the design of the code to the completion of the production cycle. Today, digital technologies for theatre, such as body scanning, motion tracking and emotion recognition, offer stage artists the ability to tap into a multitude of resources.

7.1. Body-scan technologies

Body scanning technology can produce a clone of a human being with a high degree of realism. Once the 3D model is obtained, it can be animated using a rigging application that reconstructs the points and degrees of articulation of the limbs and vertebrae. This allows the model to import the characteristic data of the scanned body's movements, highlighting its postural and movement habits. The acquisition of data and movement traces is achieved using motion-tracking technologies. The following paragraphs outline some of the most significant applications of 3D body models.

7.1.1. Creation of tailor-made costumes and sets

Body-scanning technology allows actors to get precise measurements of their bodies for the creation of bespoke costumes. This not only increases the realism of theatre productions, but also allows designers to experiment with bolder and more innovative designs.

7.1.2. Special effects design

Body scan data can be used to create highly realistic special effects (SFX) that seamlessly integrate with the actor's movements. This can include the creation of imaginary creatures or scenes where characters physically transform, taking the theatre experience to a whole new level.

7.1.3. Accessibility for actors with diverse abilities

Body scanning can be particularly useful for actors with physical disabilities, enabling the creation of customised props and mobility devices that perfectly suit their needs. This opens the door to greater diversity and inclusion in the theatre world.

7.2. Motion tracking technologies

Motion tracking (MT) technology captures and records movements in real-time, making it possible to transfer and animate 3D models. Biovision Hierarchy (BVH) is one of the most popular file formats for motion capture data and has been widely adopted by the animation community. The potential uses of this technology are many and innovative.

7.2.1. Virtual choreography

Motion tracking allows actors' movements to be captured in real-time and applied to virtual characters or elements. This makes it possible to create complex choreographies in which the real and virtual worlds intertwine, enriching the dramatic scene with immersive and spectacular dynamics.

7.2.2. Recording and archiving performances

This technology makes it possible to record an entire stage performance in 3D, enabling scholars to analyse it in detail and reproduce it in immersive visualisation systems. In this way, the audience can interactively re-live the theatrical event by physically exploring the stage space. Recording the motion tracking data of a performance makes it possible to overcome its ephemeral nature and guarantee a reproduction that respects its essence as a spatial art.

7.2.3. Interaction with interactive scenic elements

Actors can interact with digitally controlled digital or physical scenic elements, amplifying the creative possibilities for directors and set designers. This generates a more immersive experience for the audience, where the boundaries between the real and the virtual dissolve.

7.2.4. Performance analysis

Motion tracking technologies can also be used to analyse actor performance, providing objective and detailed data on movements and emotions expressed. This feedback allows actors and directors to fine-tune their skills and improve the quality of their performance.

7.3. Emotion recognition technologies

Recently, MT systems have been equipped with emotion-tracking tools that read facial expressions and eye movements to fully read body language. Emotion Recognition (ER) data is crucial in bringing virtual humans to life, making them understandable and believable, and providing a valuable study model for actors to express and convey emotions to the audience.

The study of emotion, i.e. the genesis of every action and expression, has always been the focal point, the original matrix of all human behaviour. Only after having precisely identified the position, the dynamics of this generative core and the direction of this explosion of e-motion energy, is it possible to build the dramaturgical construction and position the layers of meaning and coherence of the scenic event. The entire structure of the theatrical narration derives from this internal spark of our nervous system which, placed under the magnifying glass of the stage, becomes a shared and recognisable representation and manifestation of the motions of the human soul.

In the theory of emotion, intrinsically interconnected with the theory of perception and action, the production of meaning is schematised as in Figure 3:

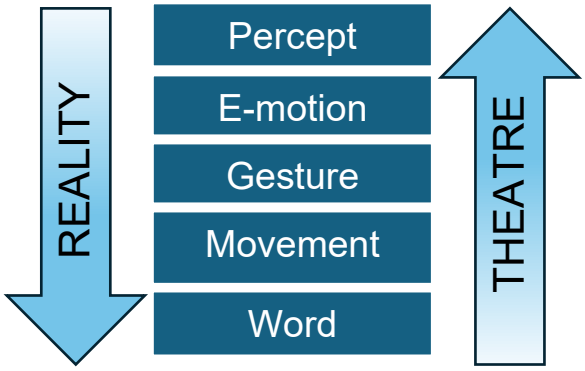


Figure 3: The path from *Percept* to *Word* in real life and backwards in theatre performance.

In real life, the percept produces a potential (e-motion) that activates muscular networks (gesture), movement and language networks, according to this temporal order.

Dramatic analysis for the stage composition and the actors' interpretation proceeds in a reverse way, from the text (word - play) or from the image (picture), to identify which movement generated the word, which gesture generated the movement, what emotion generated the gesture and from there how it was perceived among the elements present within the dramatic situation. Stage composition is the objective manifestation of perception for both actor and spectator. Interpretation is the result of a process of backpropagation.

In order to proceed to its scenic restitution, the reading of a finished work of art, a painting or a dramatic text, the process of analysis must therefore start from an objective point of reference to identify what was the perceived or external force that generated the e-motion interaction and, consequently, the response, be it of a gestural, movement or linguistic nature. This potential information, in turn, triggers a complex interaction between all the animate and inanimate objects present in the scene, modifying their degrees of resonance, behavioural conditioning and action strategies, depending on the hypotheses about the predicted evolution of the current force networks, in a constant positive tension directed towards the achievement of its purpose.

In real life human beings are in constant, simultaneous interaction with different levels of relationships; theatre identifies four main relationships: with space, with self, with others and with objects.

8. Virtual humans, robots and human actors in the contemporary theatre

Contemporary theatre is constantly evolving, driven by technological innovation and artistic research. One particularly interesting area of development is the integration of virtual humans and robots with human actors in theatre performances.

The activities of the Research Centre of the *Accademia Teatrale di Firenze* focus on the integration of avatars and digital clones of humans for teaching and performance. These tools allow us to explore complex issues such as identity and the virtual person, challenging traditional notions of individuality. Avatars, created from body scans of actors, allow the creation of hybrid performances where the real and virtual worlds merge into a single theatrical experience, allowing directors to manipulate the audience's perception and expand the boundaries of the narrative.

The use of avatars and human clones offers actors new expressive possibilities, allowing them to portray fantastic characters and explore the duality between the human and virtual worlds. Actors can use them to model a virtual self, on which to elaborate behaviours, action strategies and emotional syntax, providing a greater awareness of their own expressiveness and stage performance. Motion tracking and facial recognition sessions allow actors to analyse their movements and correct errors, making the results of a good performance verifiable and reproducible.

When the avatar of a performer is an exact model of his/her body and also captures the facial and vocal expressions, it becomes an ideal tool for dramatic teaching and research, allowing detailed analysis of emotions and micro-movements. The avatars, connected to the actors in digital space, allow them to experience different identities and psychological structures, fostering greater character identification and understanding.

The director can use the actor's avatar to explore new interpretations, changing the character's structure of thought and behaviour and offering new creative examples. This process makes it possible to elaborate new relational dynamics and experiment with different identity constructions within virtual worlds.

Virtual environments, like real ones, facilitate authentic interactions and make it possible to study how humans, avatars, computers or robots communicate. During performances, the actor can interact with avatars, humans or robots controlled by algorithms, increasing effectiveness and involvement.

In this context, the use of avatars and robots offers artists a wide range of design possibilities and new tools for creative experimentation. New technologies also make it possible to simulate complex experiences, plan preparation phases and improve concentration and interpretive effectiveness. These tools create emotionally positive experiences, expand the actors' repertoire of thoughts and actions, and contribute to the development of their creative potential.

9. Practical applications in the creation of virtual characters

Avatars created by scanning actors' bodies have a wide range of applications in performance and education, as well as research and experimentation. With the addition of AI, avatars can become autonomous and interact with their human counterparts and other avatars in a virtual environment, like Nvidia Omniverse (n.d.) which uses the power of its rendering engine to allow them to interact in real time. Thanks to the use of advanced physics simulation tools, it is possible to create a realistic virtual drama world, just like a true scenic location.

Google's Gemini (n.d.) stands out among avatar AI applications for its multimodal ability to process responses by simultaneously integrating different media, opening up new creative possibilities in the performing arts. In particular, Gemini supports artists in the creation phase by enabling digital avatars to interact and respond coherently to human conversations. Using this technology, actors can rehearse dramatic texts or improvise without the need for a physical partner, thanks to the automatic generation of dialogues based on real-time input.

The integration of recognition systems for emotions, facial expressions, physical actions and voice through neural networks (machine and deep learning) is essential to improve the interaction between actors and avatars, developing a field of research known as Emotion AI or digital empathy (Khare, Blanes-Vidal, Nadimi, & Acharya, 2024). This advanced technology is crucial for human-computer interaction (HCI) and the development of Industry 5.0, as it promotes mutual understanding between humans and robots.

The application of Emotion AI to theatre performance has three levels. The first level, analytical, aims to understand the actor's emotional and behavioural state; the second level, generative, uses a clone of the actor to simulate the character's behaviour in dramatic situations; the third level challenges the actor to bridge the gap between self and character, fostering a creative transformation that overcomes personal biases and interpretive limitations. This approach responds to historical problems of interpretation, already discussed by classical theorists such as Diderot (1773).

These tools become effective when the avatar AI possesses introspective and critical analysis skills, generating actions and dialogues in an intersubjective manner, creating unique and unrepeatable relationships with human actors. Furthermore, theatrical chatbots must be trained with a specific subjectivity that integrates the ethical shadings and cognitive patterns of the character, making the AI not just an assistant but an active co-creator in the theatrical process.

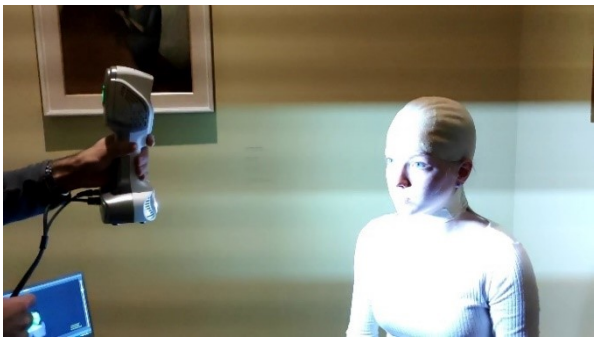
10. Before '*I Fregi del Ceppo*': experiences and results

The *Accademia Teatrale di Firenze* has been researching the integration of new digital technologies in performance art and theatre didactics for some time. Over the last few years, in collaboration with GeCO Lab, a series of immersive performances have been realised that have progressively improved the re-use of 3D data initially conceived for the documentation and conservation of cultural heritage. All the phases of conception, design, programming and editing were carried out at the *Laboratorio del Teatro Tredici* in Florence, granted by the Municipality of Florence to the *Compagnia dell'Accademia Teatrale di Firenze* for research on the integration of scenic art with new emerging digital technologies and on 3D visualisation systems for virtual environments.

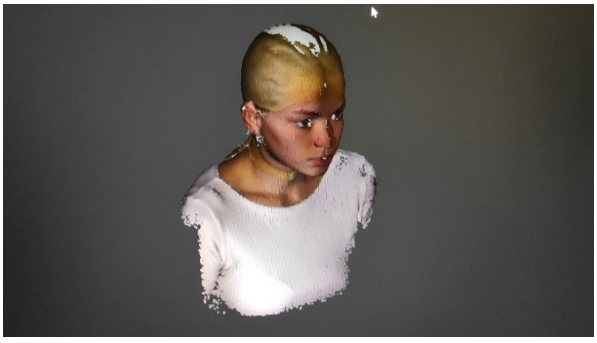
Prior to the project ‘*I Fregi del Ceppo*’, which is described in detail below, two other productions directed by Pietro Bartolini used the digital data provided by GeCO Lab:

- in 2021, “*DanXte*”, an unpublished work by Alberto Severi , stage designer Tiziana Acomanni, as part of the national celebrations of Dante, presented in the Sala d'Arme of Palazzo Vecchio in Florence in collaboration with the Municipality of Florence.
- in 2022, “*Donne attente alle donne*”, by the English playwright Thomas Middleton, as part of the 6th edition of META - Meeting of European Theatre Academies at the Teatro della Pergola in Florence.

One of the first experiments with an avatar clone of the actress Rebecca Rossini in the role of Beatrice was carried out for the DanXte show: the actress' face was digitised using a Scantech iReal 2E portable structured light scanning system (Fig. 4) and the surface model was then processed in ZBrush (n.d.) software.



(a)



(b)

Figure 4: Creation of an avatar:(a) Acquisition of the face with a hand-held scanner; (b) raw 3D model.

For the performance *'Donne attente alle donne'*, inspired by the stories of Bianca Cappello and the Grand Duke Francesco I de' Medici, virtual sets of the rooms of the Pitti Palace in Florence were created, according to the descriptions in the original script (Fig. 5).

Figure 5: The performance *Donne attente alle donne*, with point clouds used as digital scenography (photo by Chiara de Luca).

The digital scenography was created by reusing 3D point models of the Pitti Palace. The survey of the entire complex was carried out by the GeCO laboratory between 2019 and 2021 using integrated geomatics techniques, including Global Navigation Satellite System (GNSS) and total station topography, laser scanning and photogrammetry and collecting a vast amount of extremely accurate data (Tucci, Bonora, Conti, & Fiorini, 2021; Fiorini, Conti, Meucci, Bonora, & Tucci, 2023; Bonora, Meucci, & Fiorini, 2024). The availability of these models has revealed aspects of the building that had previously been overlooked, opening new research perspectives and encouraging the emergence of new professions and opportunities related to the use and reuse of digital data.

These two first experiments in the integration of 3D digital data in stage design immediately suggested various possible applications in the theatre field, not only in terms of scenography for the creation of human clones of real actors, but also opening a new field of research. Using 3D models, spatial and stage elements become numerical entities that can be interpreted and used for in-depth compositional techniques. They helped to more precisely define the influence and conditioning of the environment on the psychic dynamics of the characters, their relationships, and their behaviour.

11. How the scenic design process used 3D data

The performance '*I Fregi del Ceppo*' represents a further development in the use of digital data, which has become a constituent element of the script. The production is entirely conceived from the dramatic scenes of the ceramic friezes of the Ospedale del Ceppo, and the compositional programme was devised from scanning and photogrammetry data.

Various scenic composition possibilities were explored by studying digital models of the square, the façade of the Ospedale del Ceppo and the seven ceramic friezes. The works, which depict dramatic scenes in film-like sequences, present a simultaneous narrative: each episode appears frozen in a single frame, capturing an ideal moment that allows the viewer to read every aspect of the story.

The 25-minute site-specific production, specifically conceived for the spaces of the Sala d'Arme of the Palazzo Vecchio[1], devoted approximately three minutes to each scene. It used an existing multi-projection system consisting of seven screens arranged at 180º, combined with the presence of human performers. In the short time available, each episode had to be fully dramatised.

The first step was an in-depth analysis of the frieze images in order to structure the performance. The aim was to translate the simultaneity of the actions of the 3D characters into a textual chronological sequence, thus creating a coherent narrative chain. The analysis was carried out using traditional methods, focusing on the general composition, the posture of the figures and their relationships to each other (Fig. 6).

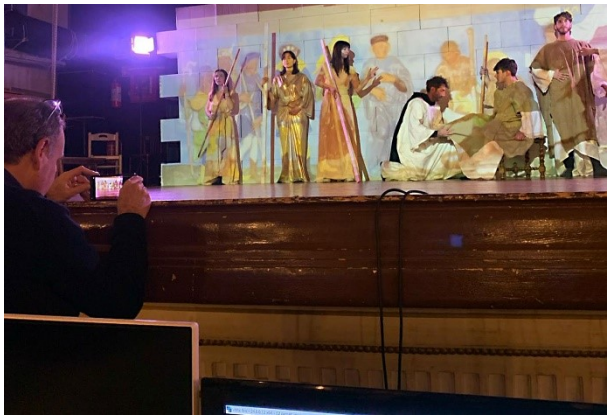


Figure 6: The director and the actors study the performance.

11.1. Compositional analysis of the friezes' dramatic scenes

Most friezes are made up of 3D figures distributed on a frontal plane, in which the only depth comes from the high relief of their bodies and the objects they hold. Only in a few cases (consoling the sick, visiting the prisoners, burying the dead) are there scenic elements that partially restore a sense of depth (Fig. 7a).

The central point of each frame is generally occupied by the protagonist, the *spedalingo* Leonardo Buonafede, who in some cases is shared with another character or with an object-symbol to further emphasise the themes expressed. The distribution of the characters is otherwise symmetrical. In the 'Hungry' frieze (Fig. 7b), the narrative is even more complicated. The scene is divided into two asymmetrical parts, in which different characters relate to two distinct protagonists. A similar compositional mode, although not as accentuated, is also found in the 'Prisoners' and 'Pilgrims' friezes.

[1] The play was conceived and performed on the occasion of the CIPA-HD 2023 International Symposium, "Documenting, Understanding, Preserving Cultural Heritage. Humanities and digital technologies for shaping the future," held in Florence from June 26-30, 2023, and replicated in March 2024 for the *Festa della Toscana*.

(a)

(b)

Figure 7: Orthophotos of two scenes: (a) *Housing the Wayfarers*; (b) *Feeding the Hungry*.

11.2. Analysis of the posture of the characters

The seven reliefs contain a total of 93 characters, each with unique somatic, expressive and postural characteristics. Most of the figures suffer from needs and their goal is to satisfy them. The protagonists, on the other hand, represent the force that transforms these needs into spiritual progress and conversion. Postural analysis refers to three main factors:

- Presuppositional situation: the character's starting condition and his desire to overcome it.
- Evaluation of the action: the posture reflects the chosen plan of action and the weighing up of its consequences.
- Conditions for action: the character, aware of his intentions, brings about a purposeful change in the given context.

Posture analysis identifies the reasons why characters activate certain objects or actions:

- Relation to space (external situation).
- Self-relation (internal situation).
- Action intentions (preparation of action patterns).

11.3. Contextualisation of the scene and its complex presuppositional situation

The scene is observed as a visual representation reflecting a frame of animated and inanimated objects and the relationships between characters. These interact within a framework that evolves through a process of adaptation, punctuated by a series of actions that reconfigure the initial situation. This cycle (current state > intention > action > new situation) creates a visual and dramatic narrative that punctuates the evolution of the interaction.

11.4. Description of the *dramatis personae* and their positional values

The analysis of movements and postures made it possible to identify the internal dynamics of the characters and the logical sequence of events. The characters' expressions were analysed using ER, which provided a basis for the construction of the dramaturgy. The collected data was then processed using a GAN algorithm trained with deep learning technologies to generate texts reflecting both the physical and emotional dynamics of the characters.

11.5. The script: Data input and usage of GAN

The outline of the script was created from orthophotos, 3D models and videos captured from the models with 3DS Max (n.d.) virtual cameras. The GAN algorithm for the dramatic composition of the performance of '*I Fregi del Ceppo*' was programmed and trained by applying different deep learning models. Detectron2 (Wu, Kirillov, Massa, Lo, & Girshick, 2019), MMDetection (Chen et al., 2019) and DETR (Carion, Massa, Synnaeve, Usunier, Kirillov, & Zagoruyko, 2020) were tested and used for scene classification, detection and segmentation, posture analysis and the study of spatial relationships. The analysis of the entire scene of each frieze was implemented using the following models: Self-Attention Module, Dual Attention Network and Scene Analyser. The introspection and sentiment analysis mechanisms were implemented using Openface (Amos, Ludwiczuk, & Satyanarayanan, 2016), Deepface (Serengil & Ozpinar, 2021) and Openpose (Cao, Hidalgo, Simon, Wei, & Sheikh, 2021). From the results obtained, narrative templates were derived and used in the textual part of the ChatGPT (OpenAI, 2023) and Google Bard (now Gemini) prompts for story structure and scriptwriting.

During the development phases of the seven drama texts, several versions of each text were produced. Each version was rehearsed and tested with the performers until a single summary was chosen as the script for the performance.

11.6. Technical characteristics of the multi-projection system and the stage of the Sala d'Arme

The multi-projection system in the Sala d'Arme consists of 14 video projectors managed by a server and seven screens with two split projections per screen. The screens are positioned along three walls of the hall and completely cover the field of vision when the audience is facing the central screen. There are three screens on the main wall (Fig. 8) and two screens on each of the two side walls. The dimensions of each screen are 7 m in base and 11 m in height, interspersed with four columns, each 1 m wide.

The total size of the projected image is 53 m x 11 m. Each screen has its own autonomous video file, and the synchronisation between the images on the different screens must be calculated in post-production.

Figure 8: The multi-projections system (from the *DanXte* show).

11.7. The storyboard

On the basis of the performance script, the design and composition phase of the show began, keeping in parallel the choreographic characteristics of the action sequences, the meanings of the text and the positional values of the characters on stage. This was followed by the storyboarding phase, which consisted of selecting images capable of reinforcing the themes expressed by the characters, synchronising them with the speech and action by keeping them as backgrounds, and positioning the virtual cameras in 3D space, with camera angles capable of highlighting the postural dynamics. The final storyboard was the result of the composition of five simultaneous storyboards.

11.8. Virtual camera movements, synchronisation with stage action, rendering and post-production

The videos of the frieze models were processed in 3DS Max with virtual camera positioning, lighting and camera movements that were consistent with the characteristics of the space, the relative moment-to-moment position of the actors and the audience's point of view in relation to the position of the screens. The friezes were treated as a film set, restricted to a single line of interest, in order to duplicate and support the dialogue between the characters with close-ups, details with high-angle fields and counter-fields, and the use of grazing lights calibrated to highlight somatic, expressive features to give greater prominence to the sculptures. The videos were edited in DaVinci Resolve (n.d.) and post-produced and dubbed in After Effects (n.d.).

11.9. The rehearsals

Each of the seven performances began with a tableau vivant, in which the actors assumed the initial positions of the characters in the frieze and then emerged from the background to begin the action. Each rehearsal was videotaped in order to synchronise the editing times according to the rhythm and dynamics of the acting. Once the cinematic composition had been worked out on the 3D models of the friezes, the synchronicity of the action with the images obtained and their expressive value were verified (Figs. 9 and 10).

Figure 9: Point clouds and mesh models used in the scenery of the show *I fregi del Ceppo*.

Figure 10: A moment of the show *I fregi del Ceppo*.

During the first part of the rehearsals, corrections and adaptations were made to the text and video processing. Once a satisfactory result had been achieved, the soundtrack was composed, and the seven compositions were combined into a single performance.

11.10. The performance at the Teatro Tredici

Due to the characteristics of the multi-projection system in the Sala d'Arme of the Palazzo Vecchio, it was not possible to project the figures of the ceramic friezes onto the bodies of the actors because of the excessive projection angle of the video projectors. As a result, the projections and the tableau vivant were placed on two levels with different depths.

The performance was then re-enacted at Teatro Tredici, adapted to the stage, with the correct positioning of the video sources, which texturised the actors' bodies as in body painting, with costumes suitable for receiving the colours of the characters in the friezes, giving the effect that the projection surface and the tableau vivant were on the same plane and that the contours coincided (Fig. 11).

Figure 11: The performance at Teatro Tredici.

12. The audience experience

Immersive theatre offers the audience a multi-sensory experience with a high degree of involvement. In the performance 'I Fregi del Ceppo', in addition to the narration of events, the audience was invited to interact with works of art and cultural heritage. This not only increased their enjoyment but also their knowledge. In this performance, the audience was guided through multi-projection systems and scenic actions in line with the projected images to observe and engage with the actors to experience the events depicted in the friezes, shown in detail from angles that would otherwise be difficult to access even with direct observation. Immersive performances related to cultural heritage works have been shown to stimulate intense emotional interactions of a historical nature and a deep connection with the territory. They also have the effect of increasing memorisation and comprehension of content, as well as triggering the activation of brain areas associated with empathy and spatial orientation.

13. Discussion

The advent of digital technologies has provided a significant boost to artistic production, with the digital industry developing innovative solutions to meet market demands. Machine learning is now influencing creativity, narrowing the gap between human and machine intelligence. This has given rise to crucial ethical and social considerations.

Art is seen as a way for humans to express themselves and share emotions. Creativity is connected to the uniqueness of the artist, as they transform perceptions into symbolic forms driven by conscious intentions. AI, lacking consciousness, is unable to generate authentic meanings and is instead viewed as a tool for artists to apply artificial neural network algorithms in the production process. However, the perspective of the audience is different. Their perceptions and responses may not align with the emotional intention of the human artist. AI algorithms, despite lacking conscious intention, can still elicit responses from the audience by generating results based on existing patterns and data, without necessarily comprehending their meanings.

Posthumanism (Braidotti, 2013) asserts that creativity arises from the interactions between humans, machines, and their environment, challenging the notion that it is exclusive to humans. This perspective regards creativity as a collaborative ecosystem facilitated by the 'distributed intelligence' model proposed by Andy Clark (1997). The perception of the audience plays a crucial role in defining the ethical principles underlying this new paradigm. Consequently, philosophical reflections are required to consider the aesthetic experience of spectators and traditional concepts of beauty and authenticity. Artists empowered by artificial creativity have the responsibility to ethically balance technological innovation with cultural values and traditional techniques. It is essential to manage the use of digital innovation, ensuring that humans do not become dominated by machines, which aim to offer countless possibilities for combination and development. Moreover, artists should maintain and refine the craftsmanship and knowledge gained throughout human history.

14. Conclusion and future prospects

This experience presented an innovative opportunity to spread knowledge about cultural heritage and activities, and the digitisation process of cultural heritage is costly and complex. The more data that can be reused, the more sustainable it is, which is why the European Union promotes the connection between cultural and creative industries and the re-use of digital data (Macrì & Cristofaro, 2021). In the current case study, the relationship between Renaissance figurative art, new digital technologies and media, and contemporary theatre production multiplies the possibility of involving a wider audience in the knowledge of different art forms.

The project '*I Fregi del Ceppo*' is a first step in this journey into the future, where artistic tradition meets technological innovation. If conceived for a virtual theatre CAVE, the 3D characters obtained from the scanned models could be animated and interact with human actors or the audience, creating a remotely controlled interactive experience.

The integration of generative intelligence into virtual characters could open further scenarios where they could tell their own story to the audience, interacting in a dynamic and personalised way. This perspective lays the foundations for a new era of the performing arts, where the art of the past evolves through digital technologies, remaining anchored to its historical roots, but projected into a future of innovation and interaction.

In short, '*I Fregi del Ceppo*' builds a bridge between artistic heritage and the potential of new technologies, demonstrating that theatre can evolve through the use of digital tools, while remaining a place for creativity and experimentation. The future is limitless, and with it the possibility of redefining the role of theatre and the performing arts in the 21st century.

Acknowledgements

The authors thank the Municipality of Florence for providing space for the performances. They also thank Mr. Joe Windley (Royal Academy of Dramatic Art) for his suggestions and revision of the translation.

This project is supported by Spoke 7 Project PE 0000020 CHANGES-CUP B53C22004010006, NRP Mission 4 Component 2 Investment 1.3, funded by the European Union–Next Generation EU. The current paper is part of CHEDAR, project of relevant international interest "Legacy Expo 2020 Dubai" (Interministerial Decree 937 of 4.8.2022), funded by the European Union–Next Generation EU.

L. Fiorini's research activity is carried out in the framework of the National PhD programme in Heritage Science (La Sapienza University of Rome and University of Florence), A. Conti's research activity is carried out in the framework of the International Doctorate in Civil and Environmental Engineering (University of Florence).

References

3DS Max (n.d.). *Autodesk 3DS Max* (Version 2023) [Computer software]. https://www.autodesk.com/products/3ds-max/

After effects (n.d.). Adobe *After Effects* (Version 23.2) [Computer software]. https://www.adobe.com/products/aftereffects.html

Bonacini, E. (2021). Storytelling digitale in ambito culturale e il suo ruolo in ambito educativo. *Culture Digitali, 0*, 85-101. https://www.diculther.it/rivista/storytelling-digitale-in-ambito-culturale-e-il-suo-ruolo-in-ambito-educativo/

Braidotti, R. (2013). *The Posthuman*. Cambridge: Polity Press.

Amos, B., Ludwiczuk, B., & Satyanarayanan, M. (2016) *Openface: A general-purpose face recognition library with mobile applications*. [Technical report] CMU-CS-16-118, CMU School of Computer Science. http://reports-archive.adm.cs.cmu.edu/anon/2016/abstracts/16-118.html

Bonora, V., Meucci, A., & Fiorini, L (2024). Analysis of the spatial-semantic coherence in the Getty AAT vocabulary data structure – An educational experience. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-2/W4-2024*, 79–85. https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-79-2024

Cao, Z., Hidalgo, G., Simon, T., Wei S.-E., & Sheikh Y. (2021). OpenPose: Realtime multi-person 2D pose estimation using part affinity fields. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *43*(1), 172-186 https://doi.org/10.1109/TPAMI.2019.2929257

Carion, N., Massa, F., Synnaeve, G., Usunier, N., Kirillov, A., & Zagoruyko, S. (2020). End-to-End Object Detection with Transformers. In: Vedaldi, A., Bischof, H., Brox, T., Frahm, JM. (Eds) *Computer Vision – ECCV 2020*. Lecture Notes in Computer Science, vol 12346 (pp. 213-229). Cham: Springer. https://doi.org/10.1007/978-3-030-58452-8_13

Chen, K., Wang, J., Pang, J., Cao, Y., Xiong, Y., Li, X., … Lin, D. (2019). *MMDetection: Open MMLab Detection Toolbox and Benchmark*. Retrieved January 6, 2025, from https://arxiv.org/abs/1906.07155. https://doi.org/10.48550/arXiv.1906.07155

Clark, A. (1997). *Being there: Putting brain, body, and world together again*. Cambridge, Ma: MIT Press. https://doi.org/10.7551/mitpress/1552.001.0001

Commission Recommendation, (2021). Commission Recommendation (EU) 2021/1970 of 10 November 2021 on a common European data space for cultural heritage. *Official Journal of the European Union*, L 401, 12.11.2021, 5–16. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2021:401:TOC

Council Conclusions, (2014). Council conclusions of 21 May 2014 on cultural heritage as a strategic resource for a sustainable Europe. *Official Journal of the European Union*, C 183/36, 14.6.2014, 36–38. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C:2014:183:TOC

Craig, E. G. (1907) The actor and the Über-Marionette. *The Mask*, *1*(2) 1908, 3-8. In E. G. Craig (2008, F. Chamberlain Ed.), *On the Art of the Theatre*. London: Routledge. https://doi.org/10.4324/9780203889749

DaVinci Resolve (n.d.). Blackmagic Design. *DaVinci Resolve* (Version 18) [Computer software]. https://www.blackmagicdesign.com/products/davinciresolve

Denard, H. (2012). A New introduction to the London Charter. In A. Bentkowska-Kafel, D. Baker & H. Denard (Eds.), *Paradata and Transparency in Virtual Heritage* (pp.57-71). London: Routledge. https://doi.org/10.4324/9781315599366

Diderot, D. (1773) *Paradoxe sur le comédien*. [First printed edition (1830) Paris: Sautelet].

Digital Library (2023). Istituto Centrale per la Digitalizzazione del Patrimonio Culturale—Digital Library. *Piano Nazionale di digitalizzazione del patrimonio culturale 2022–2023*. Versione 1.1. [National cultural heritage digitalisation plan 2022-2023. Version 1.1] https://digitallibrary.cultura.gov.it/wp-content/uploads/2023/10/PND_V1_1_2023-1.pdf

Fiorini, L., Conti, A., Meucci, A., Bonora, V., & Tucci, G. (2023): Between spatial and archival data: digital humanities for the history of a staircase of Pitti palace. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information* Sciences, XLVIII-M-2-2023, 571–577. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-571-2023

Gemini (n.d.). *Google Gemini*. [Large language model] Retrieved January 6, 2025, from https://gemini.google.com/

Henderson, J. (2006). *The Renaissance hospital: healing the body and healing the soul*. New Haven, Ct.: Yale University Press.

Italian Cultural Heritage Code (2004). Decreto Legislativo 22 gennaio 2004, n. 42 *Codice dei beni culturali e del paesaggio*. https://www.gazzettaufficiale.it/eli/gu/2004/02/24/45/so/28/sg/pdf

Khare, S. K., Blanes-Vidal, V., Nadimi, E. S., & Acharya, U. R. (2024). Emotion recognition and artificial intelligence: A systematic review (2014–2023) and research recommendations. *Information Fusion*, 102, 102019. https://doi.org/10.1016/j.inffus.2023.102019

Lehmann, H.-T. (2006). *Postdramatic Theatre*. K. Jürs-Munby (Ed.). London-New York: Routledge

London Charter (2009). *The London Charter for the computer-based visualisation of cultural heritage*. Version 2.1. https://londoncharter.org/

Macrì, E., & Cristofaro, C. L. (2021). The digitalisation of cultural heritage for sustainable development: The impact of Europeana. In P. Demartini, L. Marchegiani, M. Marchiori, G. Schiuma (Eds.), *Cultural Initiatives for Sustainable Development. Contributions to Management Science* (pp. 373-400). Cham: Springer. https://doi.org/10.1007/978-3-030-65687-4_17

Marquand, A. (1918). Unpublished documents relating to the Ceppo Hospital at Pistoia. *American Journal of* Archaeology, *22*(4), 361-377. https://doi.org/10.2307/497270

Marquand, A. (1919). The Ceppo Frieze. *Art & Life*, *11*(5), 237-244. https://doi.org/10.2307/20643777

Marra, A, Gerbino, S., Greco, A., & Fabbrocino, G. (2021). Combining integrated informative system and historical digital twin for maintenance and preservation of artistic assets. *Sensors, 21*(17), 5956. https://doi.org/10.3390/s21175956

Nawata, Y., & Dethlefs, H. J. (2022). *Performance spaces and stage technologies*. Bielefeld: transcript. https://doi.org/10.14361/9783839461129

Nvidia Omniverse (n.d.). *Omniverse Platform for OpenUSD*. Retrieved January 6, 2025, from https://www.nvidia.com/en-us/omniverse/

OpenAI. (2023). ChatGPT (GPT-3.5 2023 version) [Large language model]. Retrieved January 6, 2025, from https://chat.openai.com/chat

Pizzo, A., Lombardo, V., & Damiano, R. (2019). Algorithms and interoperability between drama and artificial intelligence. *TDR/The Drama Review*; *63*(4(244)), 14–32. https://doi.org/10.1162/dram_a_00872

Quintero, M. S., Blake, B., & Eppich, R. (2007). Conservation of architectural heritage: The role of digital documentation tools: The need for appropriate teaching material. *International Journal of Architectural Computing, 5*(2), 239-253. https://doi.org/10.1260/1478%2D0771.5.2.240

Serengil S. I. & Ozpinar, A. (2021). HyperExtended LightFace: A Facial Attribute Analysis Framework. *2021 Int. Conference on Engineering and Emerging Technologies (ICEET)* (pp. 1-4). https://doi.org/10.1109/ICEET53442.2021.9659697

Tucci, G., Bonora, V., Conti, A., & Fiorini, L. (2015). Benchmarking range-based and image-based techniques for digitizing a glazed earthenware frieze. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, II-5/W3*, 315–322. https://doi.org/10.5194/isprsannals-II-5-W3-315-2015

Tucci, G., Bonora, V., Conti, A., & Fiorini, L. (2017). High-quality 3D models and their use in a cultural heritage conservation project. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W5*, 687–693. https://doi.org/10.5194/isprs-archives-XLII-2-W5-687-2017

Tucci, G., Bonora, V., Conti, A., & Fiorini, L. (2021). How were the tapestries in the sala di Saturno of Pitti Palace arranged? Geomatics and virtual reality for art curators. In *Proceedings of the joint international event 9th ARQUEOLÓGICA 2.0 & 3rd GEORES*, (pp. 436-442). Valencia: Universitat Politècnica de València. https://doi.org/10.4995/Arqueologica9.2021.12175

Wu, Y., Kirillov, A., Massa, F., Lo, W-Y., & Girshick, R., (2019). *Detectron2*. (Version 0.6) [Computer software]. https://github.com/facebookresearch/detectron2

ZBrush (n.d.). *Maxon ZBrush* (Version 2023.0.1) [Computer software]. https://www.maxon.net/en/product-detail/zbrush