



**National  
Technical  
University of  
Athens**

School of Rural and Surveying Engineering  
MSc Geoinformatics

# DEVELOPMENT AND EVALUATION OF VIRTUAL REALITY TECHNOLOGY FOR THE NTUA CAMPUS

**Dimitrios Vitanoglou**

**Supervisor: Dimopoulou Efi,  
Professor at NTUA**

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# NATIONAL TECHNICAL UNIVERSITY OF ATHENS

We certify that we have read this dissertation and approved it as adequate in scope and quality. We have found that it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.

## Dissertation Committee

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Dimopoulou Efi, Professor at NTUA, Committee Chair

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Georgopoulos Andreas, Professor at NTUA, Committee Member

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Photis Georgios, Professor at NTUA, Committee Member

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Date

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## Abstract

The intention of this dissertation is to develop and evaluate a Virtual Reality technological tool for the campus of National Technical University of Athens. After thorough theoretical research and practical investigation on virtual tour software and applications we are going to develop an open-source virtual tour for the campus. Using this tool, visitors will have the ability to easily navigate anywhere within the campus, and get information regarding the most important campus facilities.

## Περίληψη

Πανοραμικές φωτογραφίες ή εικόνες ευρείας γωνίας είναι αυτές που απεικονίζουν οριζόντια επιμήκη οπτικά πεδία ή οπτικά πεδία ευρύτερα από το φυσικό ανθρώπινο οπτικό πεδίο και μπορούν να ταξινομηθούν σε 3 τύπους: το κυλινδρικό, το σφαιρικό/κυβικό και το επίπεδο πανόραμα. Και οι τρεις τύποι μπορούν να είναι είτε συμβατικοί 2D, είτε στερεοσκοπικοί 3D. Στο πλαίσιο αυτής της διατριβής, θα επικεντρωθούμε στους συμβατικούς 2D τύπους και πιο συγκεκριμένα στα σφαιρικά/κυβικά πανοράματα.

Πανοραμικές λήψεις μπορούν να ληφθούν είτε με αναλογικές, είτε με ψηφιακές κάμερες. Ωστόσο, για τη δημιουργία εικονικής περιήγησης 360°, χρησιμοποιούνται μόνο ψηφιακές φωτογραφικές μηχανές. Μπορούν να χρησιμοποιηθούν είτε απλές ψηφιακές φωτογραφικές μηχανές (π.χ. DSLR) για τη λήψη φωτογραφιών οι οποίες στην συνέχεια θα συρραφθούν για να δημιουργηθούν τα πανοράματα είτε 360° σφαιρικές ψηφιακές φωτογραφικές μηχανές 360° για ευκολότερη ροή εργασίας.

Με τις σφαιρικές ψηφιακές φωτογραφικές μηχανές 360°, η διαδικασία δημιουργίας πανοραμάτων γίνεται πολύ πιο απλή και γρήγορη. Χρησιμοποιώντας κανονικές ψηφιακές φωτογραφικές μηχανές, χρειάζεται αρκετή επεξεργασία προκειμένου να συρραφτούν όλες τις φωτογραφίες μαζί και να δημιουργηθεί μια εικονική περιήγηση. Ωστόσο, οι σφαιρικές ψηφιακές φωτογραφικές μηχανές 360° σαρώνουν 360° με 180° σφαιρικά πλαίσια με ένα κλικ και επεξεργάζονται τις εικόνες αυτόματα μέσα στην κάμερα. Η εφαρμογή που περιγράφεται σε αυτή τη διατριβή δημιουργήθηκε χρησιμοποιώντας τη Ricoh Theta S, μια 360° σφαιρική ψηφιακή φωτογραφική μηχανή που έχει δύο κάμερες και δύο αισθητήρες που φωτογραφίζουν ταυτόχρονα σε αντίθετες κατευθύνσεις.

Η εικονική πραγματικότητα είναι μια τεχνολογία που επιτρέπει στους χρήστες να αλληλεπιδρούν με ένα εξομοιούμενο σε υπολογιστή περιβάλλον (Burdea, G. και P. Coffet, 2003). Χρησιμοποιεί περιβάλλοντα πολλαπλών προβολών για τη δημιουργία ρεαλιστικών εντυπώσεων και αισθήσεων (π.χ. εικόνων, ήχων κλπ.) που προσομοιώνουν τη φυσική παρουσία ενός χρήστη σε ένα εικονικό ή φανταστικό περιβάλλον. Ένας χρήστης εξοπλισμού εικονικής πραγματικότητας είναι σε θέση να "κοιτάξει γύρω" τον τεχνητό κόσμο, να κινηθεί γύρω και ενδεχομένως να αλληλεπιδράσει με εικονικά χαρακτηριστικά ή αντικείμενα.

Η βάση της εικονικής πραγματικότητας, όπως εμφανίζεται σήμερα, διαμορφώθηκε στα τέλη της δεκαετίας του 1960 και της δεκαετίας του 1970, με πρώιμες εικονικές προβολές (Sutherland, 1965), αλλά μόνο στα μέσα της δεκαετίας του 1980 συνέκλιναν πολλές ειδικές τεχνολογίες για να δημιουργήσουν ολοκληρωμένα συστήματα εικονικής πραγματικότητας. Ένα τρισδιάστατο εικονικό χώρο στον οποίο ο χρήστης θα μπορούσε να αλληλεπιδράσει και να χειριστεί 3D γραφικά αντικείμενα με χειρονομίες ανέπτυξε το MIT (Scmandt, 1983), ενώ η NASA δούλευε στο έργο VIVED (Virtual Visual Environment Display) και έπειτα στο VIEW (Virtual Interactive Environment Workstation). Η έρευνα της NASA επικεντρώθηκε κυρίως σε τομείς όπως ο έλεγχος τηλεπισκόπησης και η διαχείριση μεγάλης κλίμακας συστημάτων πληροφοριών και στόχευε στη δημιουργία διεπαφής πολλαπλών λειτουργιών και πολλαπλών μεταφορέων για τη διευκόλυνση της φυσικής αλληλεπίδρασης με σύνθετα επιχειρησιακά καθήκοντα και την αύξηση της ευαισθητοποίησης των φορέων εκμετάλλευσης σχετικά με μεγάλης κλίμακας αυτόνομα ολοκληρωμένα συστήματα (Fisher, 1986). Η εικονική πραγματικότητα δεν εισήχθη στο ευρύ κοινό μέχρι το 1989, όταν η VPL Research και η Autodesk λάνσαραν συσκευές και οθόνες για την αλληλεπίδραση με εικονικούς κόσμους. Από τότε, η έρευνα σε πολλούς τομείς εικονικής πραγματικότητας οδήγησε στην ανάπτυξη εφαρμογών και εργαλείων που μπορούν να χρησιμοποιηθούν σε πολλά επιστημονικά πεδία, όπως η ιατρική, η χημεία, η επιστημονική απεικόνιση κλπ., προσθέτοντας όχι μόνο θεωρητική γνώση αλλά και πρακτική αξία (Balaguer, 1996).

Η τεχνολογία της εικονικής πραγματικότητας έχει εξαπλωθεί στον κόσμο της φωτογραφίας, με την φωτογραφία εικονικής πραγματικότητας να γίνεται ένα όλο και πιο δημοφιλές υποπεδίο. Ορίζεται ως η διαδραστική προβολή πανοραμικών φωτογραφιών ή βίντεο ευρείας γωνίας, που συνήθως καλύπτουν έναν σφαιρικό πανόραμα 360° ή μια σφαιρική όψη (Mohammad Hafiz Ismail, 2009). Περιλαμβάνει τη λήψη ή τη δημιουργία, με τη βοήθεια του κατάλληλου λογισμικού, μιας ευρείας προβολής ως ενιαίας εικόνας, όπως θα παρατηρείτο με την περιστροφή γύρω από μια συγκεκριμένη θέση. Μια εντυπωσιακή πανοραμική φωτογραφία είναι αυτή που εκτίθεται με τρόπο που επιτρέπει στους χρήστες να αλληλεπιδρούν με τις γύρω απόψεις της.

Η εξέλιξη της φωτογραφίας εικονικής πραγματικότητας είναι η σχετικά νέα τεχνολογία των εικονικών περιηγήσεων. Εικονική περιήγηση είναι η προσομοίωση μιας υπάρχουσας περιοχής και αποτελείται συνήθως από μια ακολουθία εικόνων ή βίντεο,

παρουσιάζοντας τις γεωμετρικές ιδιότητες της τοποθεσίας και παρέχοντας πληροφορίες μέσω πολυμέσων, παρέχοντας στους χρήστες ένα συναίσθημα περιπλάνησης, την εντύπωση ότι κινούνται στο χώρο και ότι βρίσκονται σε πραγματικό χρόνο (Colasante Meg, 2011). Χρησιμοποιώντας τεχνικές και χαρακτηριστικά που αντιπροσωπεύουν με ακρίβεια μια τοποθεσία, δηλαδή την ακριβή απεικόνιση όλων των οντοτήτων (π.χ. κτίρια, αντικείμενα, εγκαταστάσεις κλπ.), την ακριβή διάταξη και ένα υψηλό επίπεδο αλληλεπίδρασης με τον χρήστη για τον έλεγχο και την ελεύθερη πλοήγηση στο εικονικό περιβάλλον, μια εικονική περιήγηση μπορεί να καταφέρει να προσφέρει στον χρήστη μια εμπειρία παρόμοια με την επίσκεψη στην πραγματικό χώρο.

Οι εικονικές περιηγήσεις δίνουν στους χρήστες την αίσθηση ότι βρίσκονται σε μια τοποθεσία, οπουδήποτε στον κόσμο, χωρίς να τις επισκέπτονται, και τους επιτρέπουν να αλληλεπιδρούν ουσιαστικά με το χώρο και να ανακαλύπτουν λεπτομέρειες με ένα απλό κλικ ενός ποντικιού. Οι πανοραμικές εφαρμογές 360° επιτρέπουν στους χρήστες να πλοηγηθούν προς οποιαδήποτε κατεύθυνση, να προβάλουν έναν πλήρη κύκλο μιας θέσης και να μετακινηθούν κάνοντας κλικ στα υπάρχοντα hotspots. Η σύνδεση των εικόνων μεταξύ τους, επιτρέπει την πλοήγηση σε όλη τη περιοχή μέσα στην εφαρμογή, ενώ η κάτοψη του χώρου (πχ. χάρτης) δημιουργεί ένα περιβάλλον φιλικό προς το χρήστη, εύκολο στην πλοήγηση.

Οι εικονικές περιηγήσεις μπορούν να χρησιμοποιηθούν ακριβώς ως μια καινοτόμος τεχνική που επιτρέπει στους ανθρώπους να επισκέπτονται τα μέρη εξ αποστάσεως σε ένα ψηφιακό περιβάλλον, σε διαδικτυακές εφαρμογές. Ακόμα μπορούν να χρησιμοποιηθούν για τη δημοσιοποίηση εγκαταστάσεων μέσω της συμμετοχής σε μια διαδραστική εμπειρία. Για το λόγο αυτό, καθίστανται ένα σημαντικό ηλεκτρονικό εργαλείο σε πολλές βιομηχανίες όπου ο παράγοντας τοποθεσία διαδραματίζει σημαντικό ρόλο. Οι βιομηχανίες που μπορούν να ωφεληθούν περισσότερο από αυτή τη νέα τεχνολογία είναι οι τουριστικές και πολιτιστικές βιομηχανίες, τα πανεπιστήμια, καθώς και ο τομέας διαχείρισης ακινήτων.

Οι υποψήφιοι φοιτητές ενός πανεπιστημίου αλλά και οι επισκέπτες συχνά μπερδεύονται με τη διάταξη των εγκαταστάσεων της πανεπιστημιούπολης και δαπανούν πολύ χρόνο προσπαθώντας να βρουν πως θα περιηγηθούν σε αυτή. Αρχικά, συστήματα δορυφορικής πλοήγησης και αργότερα νέες τεχνολογικές εξελίξεις, όπως το Google Maps παρείχαν κάποια λύση σε αυτά τα προβλήματα, αλλά ήταν η εισαγωγή της εικονικής περιήγησης, όπως το Google Street View, που

βελτίωσε περαιτέρω την οπτικοποίηση και χωρική κατανόηση κάποιων πανεπιστημιούπολεων. Ως εκ τούτου, διαδικτυακές διαδραστικές εικονικές περιηγήσεις γίνονται όλο και πιο δημοφιλείς λόγω της χρησιμότητάς τους, και καθίσταται αναγκαίο για τα πανεπιστήμια να παρέχουν τέτοιες περιηγήσεις με σκοπό τη διευκόλυνση των επισκεπτών στο να κατανοήσουν καλύτερα το χώρο της πανεπιστημιούπολης.

Οι διαδραστικές εικονικές περιηγήσεις, χωρίζονται σε δύο τύπους: οριζόντιες πανοραμικές και πανοραμικές 360°. Οι οριζόντιες πανοραμικές περιηγήσεις προσφέρουν όψη σε έναν οριζόντιο άξονα, επιτρέποντας αριστερή και δεξιά πλοήγηση για προβολή συνεχών φωτογραφιών γύρω από μια τοποθεσία. Οι περιηγήσεις 360° παρέχουν μία πλήρη 360° θέαση (συμπεριλαμβανομένης της προς τα πάνω και προς τα κάτω πλοήγησης), προσφέροντας στους χρήστες πλήρη έλεγχο του τι βλέπουν και πώς αλληλεπιδρούν με το χάρτη. Εξακολουθούν να υπάρχουν ορισμένα ήσσονος σημασίας ζητήματα, όπως το γεγονός ότι οι θεατές μπορούν να δουν μια περιοχή μόνο από μια συγκεκριμένη θέση, από την οποία λήφθηκε η φωτογραφία, αλλά συνολικά, σε σύγκριση με τους προηγούμενους τύπους περιήγησης, μια εικονική περιήγηση προσφέρει μια πολύ καλύτερη λύση, επιτρέποντας τους χρήστες να αλληλεπιδρούν με το περιβάλλον σε αντίθεση με την απλή παρατήρηση του. Ορισμένα πανεπιστήμια που παρέχουν εικονικές περιηγήσεις στις πανεπιστημιούπολεις στις ιστοσελίδες τους είναι το Πανεπιστήμιο Heriot-Watt, το Πανεπιστήμιο της Οξφόρδης και το Πανεπιστήμιο του Newcastle.

Η Πολυτεχνειούπολη του Εθνικού Μετσόβιου Πολυτεχνείου δεν είχε μέχρι στιγμής καμία εικονική περιήγηση και έχανε μια μεγάλη ευκαιρία να προσφέρει στους επισκέπτες της, τους υποψήφιους και τους τρέχοντες φοιτητές της, μια επιμελημένη εμπειρία και να τους βοηθήσει να απεικονίσουν τους εαυτούς τους ως μέρος της ζωής της πανεπιστημιούπολης. Η Πολυτεχνειούπολη του ΕΜΠ για την οποία δημιουργήθηκε η εικονική περιήγηση βρίσκεται στην περιοχή του Ζωγράφου, στην πόλη της Αθήνας. Καταλαμβάνει έκταση 900.000 τετραγωνικών μέτρων και περιλαμβάνει σύγχρονα κτίρια εξοπλισμένα με αίθουσες διδασκαλίας, εργαστήρια, βιβλιοθήκες, κτίρια διοικητικών υπηρεσιών, εγκαταστάσεις φροντίδας σπουδαστών και άλλες λειτουργίες. Η εικονική περιήγηση που δημιουργήθηκε περιλαμβάνει ολόκληρη την Πολυτεχνειούπολη εξωτερικά των κτιρίων και ένα δίκτυο μήκους 13.000 μέτρων, συμπεριλαμβανομένων των δρόμων και πεζοδρομίων, των χώρων στάθμευσης και της κεντρικής πλατείας.

Η ανάπτυξη της εικονικής Πολυτεχνειούπολη του ΕΜΠ ακολούθησε τα παρακάτω στάδια:

1. Σχεδιασμός και Λήψη: κατά τη διάρκεια αυτού του σταδίου, καθορίστηκαν οι θέσεις από όπου θα γίνονταν οι λήψεις, επιλέχθηκε ο εξοπλισμός που θα χρησιμοποιούταν και διευθετήθηκαν όλες οι άλλες λεπτομέρειες λήψης.
2. Επιλογή Λογισμικού: κατά τη διάρκεια αυτού του σταδίου, ερευνήθηκαν και ελέγχθηκαν πολλά διαφορετικά εργαλεία δημιουργίας εικονικής περιήγησης και επιλέχθηκε το καταλληλότερο.
3. Ανάπτυξη και Σχεδιασμός: κατά τη διάρκεια αυτού του σταδίου, η εφαρμογή συναρμολογήθηκε, χρησιμοποιώντας τον κώδικα που λήφθηκε από το λογισμικό που επιλέχθηκε.

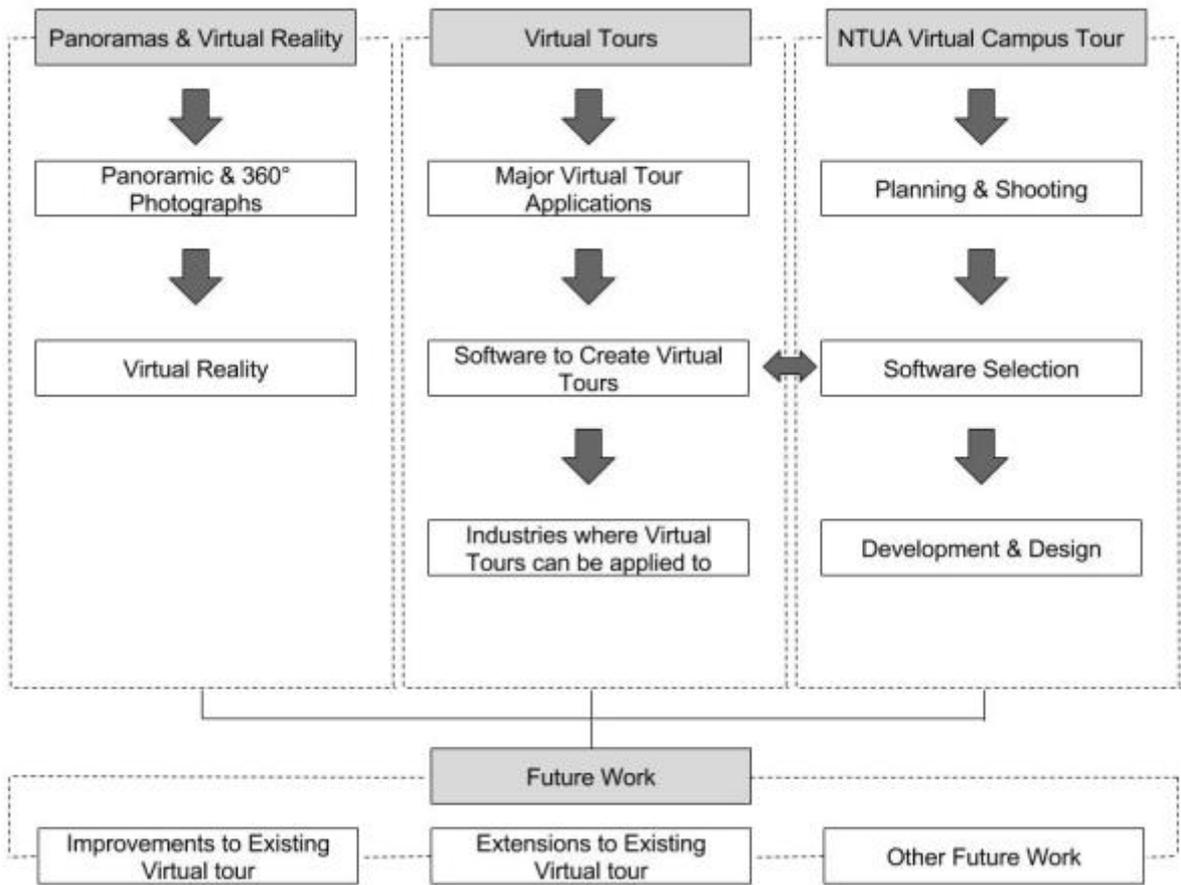
Η εφαρμογή εικονικής περιήγησης της Πολυτεχνειούπολης του ΕΜΠ που αναπτύχθηκε ως μέρος αυτής της εργασίας, προσφέρει πολλές δυνατότητες για περαιτέρω βελτίωση και ανάπτυξη. Είναι ένα πολύ χρήσιμο εργαλείο που κάλυψε την ανάγκη για τεχνολογική πρόοδο στον τομέα της χωρικής περιγραφής. Ωστόσο, πολλές από τις πτυχές αυτής της έρευνας αξίζει να εξεταστούν περαιτέρω και υπάρχουν κάποιες ιδέες για πρόσθετες βελτιώσεις και επεκτάσεις.

## 1. Introduction

This dissertation aims to define and elucidate terms such as Virtual Reality, Panoramic Photography and Virtual Tours, and to present and analyse the development of a web-based virtual tour for the campus of National Technical University of Athens. The purpose of this virtual tour application is for users to have the ability to easily navigate anywhere within the campus, and get information about the most important campus spots.

The first section of the dissertation is occupied with a small history of panoramas, the types of cameras and ways for shooting vistas, and an introduction to virtual reality. The second section provides a more thorough analysis of virtual tours. Various software tools for creating virtual tours are presented and assessed, and major virtual tour applications are described. Furthermore, the many functions of virtual tours in various industries are discussed, and an assessment of their potential value in marketing universities and their campuses is given.

The final section is engaged with explaining the design and development of the case study at hand, namely the National Technical University of Athens campus virtual tour, along with all the stages of the project, starting from the planning and the shooting, continuing to the research for the software selection, and concluding with the actual development process.



## 2. Panoramas and Virtual Reality

### 2.1 Panoramic – 360° Photographs

The word “panorama”, according to the Merriam-Webster’s dictionary, is a combination of two Greek words, the suffix “pan” which means “all” and “orama” which means “sight”, and is any wide-angle view or representation of a physical space, whether in painting, drawing, photography, film, seismic images, or a three-dimensional model. Even though cartographic experiments during the Enlightenment years contributed in forming an urge towards panoramic depiction, it was English painter, Robert Barker who originally conceived the idea of a panorama, and actually received a patent for it in 1767, to describe his style of work, which included paintings that practically surrounded the audience (Stephan Oettermann, 1997). A panoramic painting’s goal was a depiction of the real world so realistic that the viewers would get the impression of standing in a new environment.

By the mid-19th century, panoramic paintings (especially large scale installations) became a very popular way to represent landscapes, topographic views, and historical events. But, the introduction of the Daguerreotype, and subsequent, improved models, allowed panoramic photography to displace panoramic painting, in the late-19th century, as the most common method for creating wide views and giving an audience the chance to view places that they had never visited before (Stephan Oettermann, 1997).

Photographers began assembling multiple images of a view into a single wide image, using the camera to capture what the viewer would see if he was actually standing in a certain spot, and what he would see if he moved his head from side to side – thus taking in all the detail of the scene that surrounded him. Early pioneers compiled multiple daguerreotype plates side by side, separately exposed and processed, in order to form a panorama. Each image was carefully captured, with the edges of its frames always noted in order to connect it with the next. Once the photograph was taken, the camera was rotated to the edge of the frame, a new plate was installed and the ensuing photograph was taken. The same process was followed by photographers after the introduction of the wet-plate collodion system that followed Daguerreotype.

In 1890s, with the invention of flexible film and several other equipment designed for wide-image capturing, panoramic photography was revolutionised (Eric Renner, 2008). The new models eradicated the need for multiple image shooting, covered whole vistas in a single picture, greatly enhanced the photograph quality, and followed, for the most part, one of these designs:

- Short Rotation (or Swing Lens): these cameras had a static, curved film and a rotating lens that moved from side to side on a pivot system.
- Full Rotation: more complex in design, these cameras had both the film and lens rotating from a central point, and were capable of 360° rotation, capturing the whole scene in a single movement.

Most mass-produced panoramic cameras followed the swing-lens style, and produced small panoramas, measuring approximately 30 cm with an 180° field of view.

These early wide-angle cameras have, until today, kept in principal the same design, but have received enhancements in many areas, with improved lenses, camera bodies and film-transport mechanisms. Modern film-based panoramic cameras continue to thrive, are of high-quality and can capture vistas with a great amount of fine details. It should be noted, however, that unlike conventional cameras, many panoramic ones produce distorted images as the distance between the lens and the subject changes.

In the digital age, with the need of digital panoramas for a broad range of web and mobile applications, the use of digital 360° cameras, using two back-to-back lenses shooting at the same time, or conventional digital cameras, taking series of photos and then stitching them together to create panoramas in specially designed software, is more widespread.

### 2.1.1 Panoramic Formats

Panoramic, or wide format photographs are pictures that depict horizontally elongated fields of view, or pictures that depict a field of view that is wider than the natural human field of view, and can be classified into 3 types: the cylindrical, spherical/cubical and planar panoramas. All 3 types can be either conventional 2D, or stereoscopic (3D Panoramas) (Frich, A. 2007). In the scope of this dissertation,

we will focus on conventional 2D, and most particularly spherical/cubical panoramas, although all other types are briefly described below.

#### *2.1.1.1 Planar Panoramas*

A Planar Panorama is a panoramic photo that is produced by the combination of a series of frames (Figure 1). This method is mainly used in cases where the other two methods cannot be used (e.g. streets or building groups). The camera is positioned halfway along the subject until the whole subject is captured (Carmichael, G. 2009).

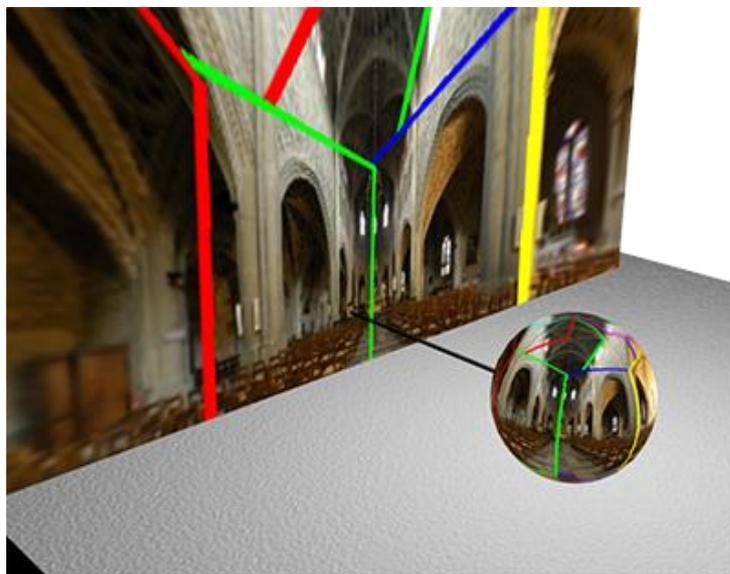


Figure 1: Planar Panorama

#### *2.1.1.2 Cylindrical Panoramas*

Cylindrical panoramas, used primarily in stills photography, depict a 360° horizontal field of view that has vertical constraints, depending on the equipment used or the editing of the image. If flattened out, straight horizontal lines in reality become curved, while straight vertical lines remain straight. There are two types of cylinder panoramas. In the case of inner-cylinder panoramas the setting of the camera stays fixed, and the picture is formed through rotating the 360° camera. In the case of outer-cylinder panoramas the subject is kept fixed and the camera takes photos of the whole circle of the subject. A cylindrical panorama is intended to be viewed as if it were wrapped into the shape of a cylinder and viewed from within (Ang Tom, 2008) (Figure 2).



Figure 2: Cylindrical Panorama

### *2.1.1.3 Spherical Panoramas*

Spherical panoramas are mainly used for virtual-reality purposes and they show the entire field of view from a single point, 360° horizontally and 180° vertically, allowing the viewer to look in every direction, including the highest and lowest point (Ang Tom, 2008). The image is wrapped into a sphere and viewed from the centre. The horizontal direction of a spherical panorama is distorted when flattened. The same thing happens to the vertical direction, to a lesser extent. A spherical panorama can be flattened and stretched to become cubic, each cube face representing a planar image that looks normal to the human eye (Figure 3).



Figure 3: Spherical panorama

#### 2.1.1.4 Stereoscopic Panoramas

Stereoscopic photos are pairs of images, taken simultaneously with two lenses corresponding to the two human eyes, looking in the same direction. When viewed with a stereoscope, such as a View Master, these images create an impression of depth and solidity and give viewers the impression of seeing a 3D space (Toeppen S.J. & Buchheim J. 2013). This can be applied to the case of panoramas of any type, with the combination of a pair of 360° images, which when viewed with synchronized Panorama viewers presents a stereo pair. The most popular stereoscope for viewing stereo panoramas is a virtual reality headset (Figure 4).

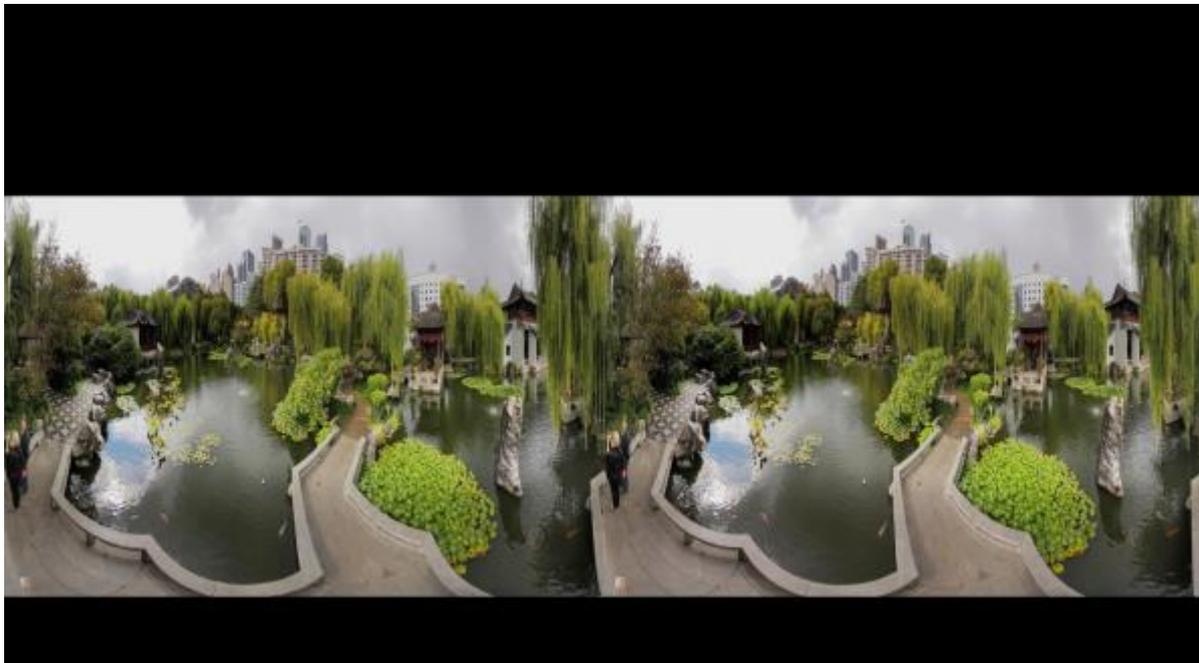


Figure 4: Stereoscopic panorama

#### 2.1.2 Types of Camera Shooting

Panoramic vistas can be captured either with analogue (film) cameras, or with digital ones. However, for 360° Virtual Tour purposes, only digital cameras can be used: Normal digital cameras (e.g. DSLR) can be used to shoot pictures, and then create panoramas by stitching the frames together using specially designed software, or 360° spherical digital cameras can be used to shoot 360° photographs straight for a faster workflow.

### 2.1.2.1 Digital camera

#### Shooting

Any digital camera can be used to shoot photographs to be stitched into panoramas (Figure 5). However, a tripod and a panoramic pan head should be used whenever possible to prevent parallax and guarantee an overlap between frames to overcome lens distortion and have enough detectable features (Kerr Douglas, 2005). Identical exposures are also required, in order for seamless results to be produced. In order to shoot a full  $360^\circ$  by  $180^\circ$  vista, the ensuing process is followed. Initially, the first set of images is captured in a straight horizontal plane, each frame shot with the camera rotated by  $36^\circ$  until the row is completed. Next, two sets of images are captured, with the camera tilted first upwards and then downwards by a  $45^\circ$  angle (Figure 6). Finally, another two sets of images are captured, this time with the camera tilted first upwards and then downwards by a  $90^\circ$  angle, in order to depict the highest and lowest points of the panorama and ensure a successful merging with the rest of the images (Figure 7).

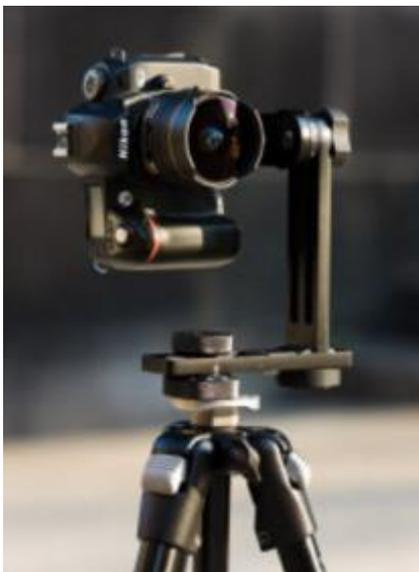


Figure 6: Digital camera

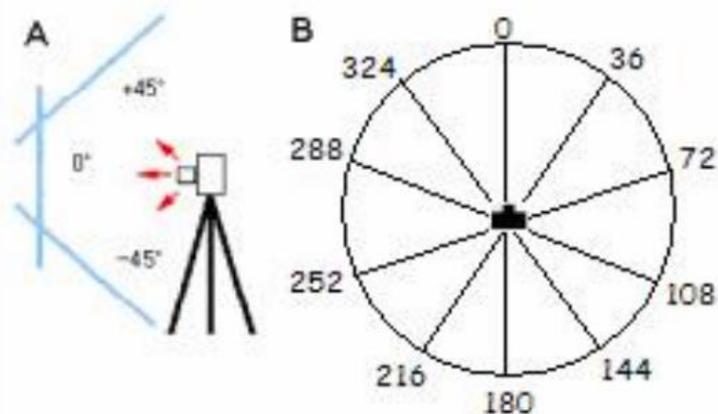


Figure 5 : Techniques of capturing images A) image planes and the camera B) 10 images per  $360^\circ$

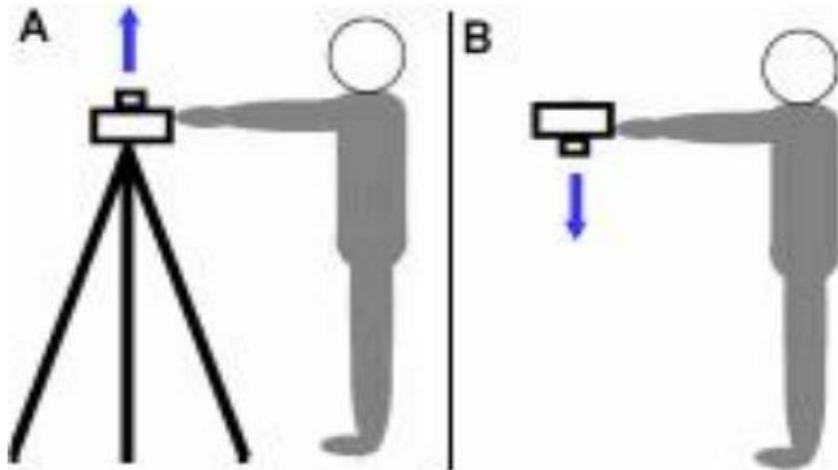


Figure 7: Techniques of capturing images A) straight up B) straight down

### Stitching Images

The stitching process in order to create panoramic vistas, requires all the images to be uploaded in a specially designed software (such as PTGUI, AutoStitch, Hugin). Then, there are two stitching methods that can be used. The first method is highly automated, with the frames being connected to each other with the help of a pattern matching algorithm. This method works better in cases of still panoramas, as moving scenes may confuse the alignment process (e.g. cars moving on the road, clouds moving in the sky, etc) (Figure 8).

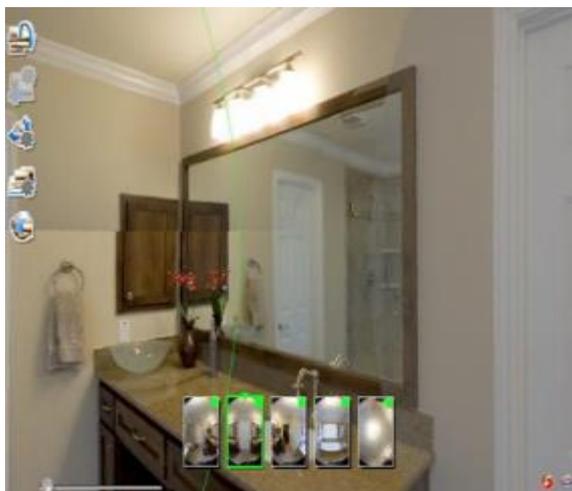


Figure 9: Fail automatic stitching algorithm

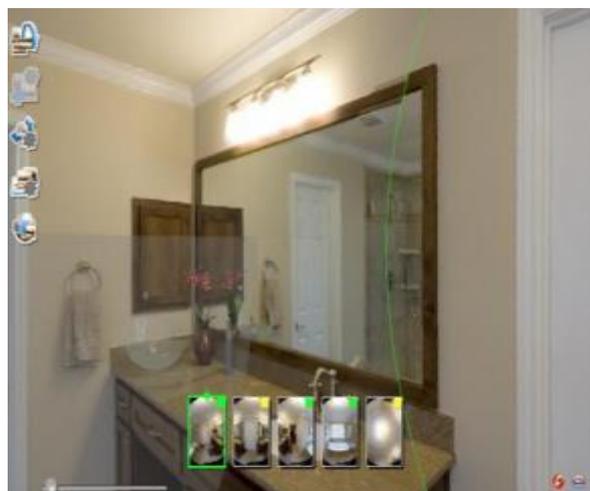


Figure 8: Manual stitching

The second method includes manual stitching of the frames, and is used when the first method does not produce the desired results. The manual method allows the user to select control points in the frames to facilitate the stitching procedure (Figure 9). To follow this method, two similar frames are selected, one of which is already previously stitched to a third frame. Then, markers are assigned manually on respective points in each frame (Figure 10 & Figure 11), and the frames are stitched together by the software (Figure 12).

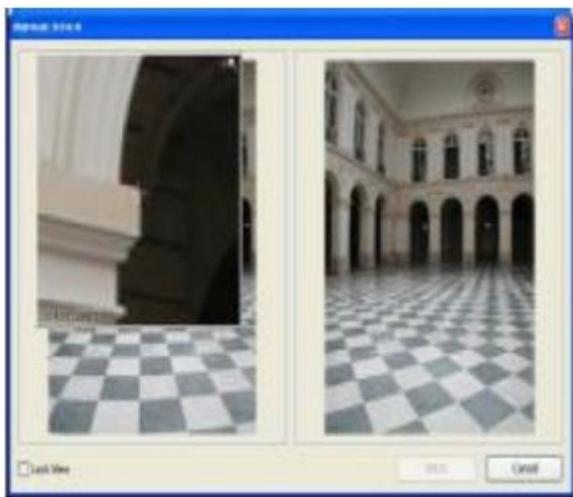


Figure 11: Placing the first marker



Figure 10: Placing the second marker

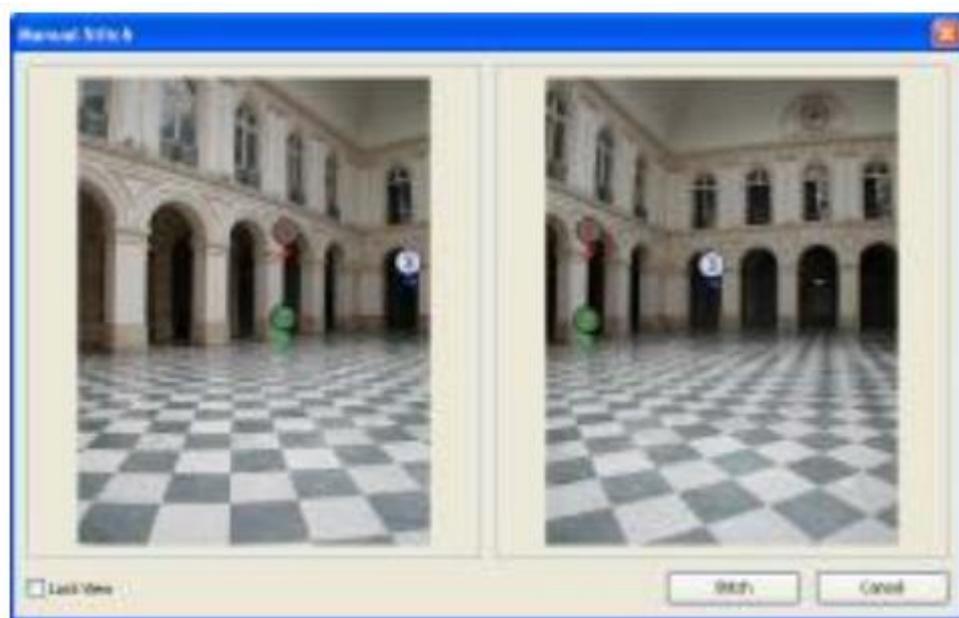


Figure 12: Stitched images

## Creating Panoramas

When the image stitching stage is complete, the panoramas are generated and ready to be rendered and extracted into many different formats, such as .jpg, .png, .mov, .tiff, .tga, etc.

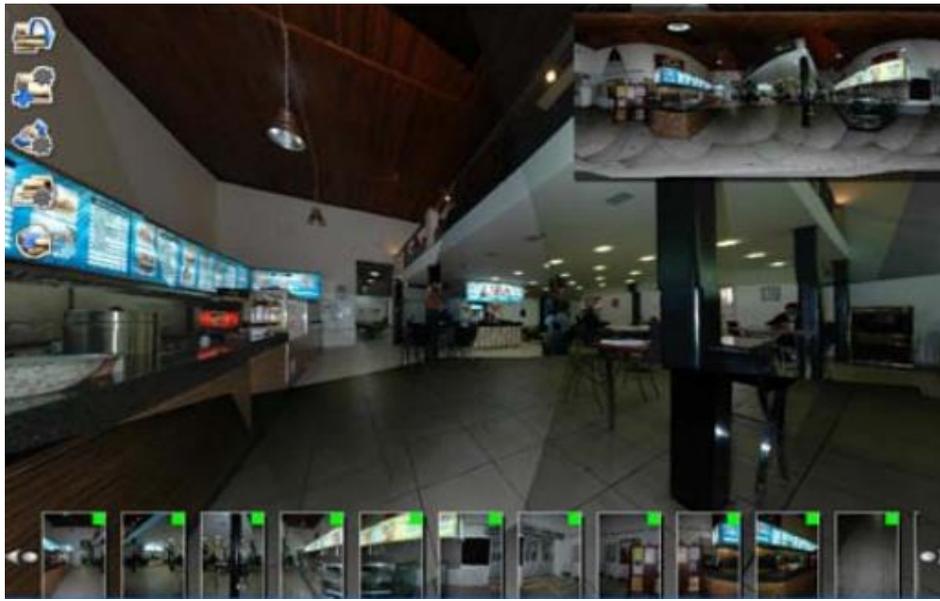


Figure 13: Example of a panorama generated by rendered stitched

### *2.1.2.2 360° spherical digital camera*

With a 360° spherical digital cameras, the process of creating a panorama becomes much simpler and quicker. When using normal digital cameras there is a lot of post-processing work involved, in order to stitch all the images together and produce a virtual tour. But 360° spherical digital cameras shoot 360° by 180° spherical frames in one click, and process the images within the camera. The application that is described in this dissertation was created by using Ricoh Theta S, a 360° spherical digital cameras which has two cameras and two sensors that shoot in opposite directions (Figure 14 & 15).



Figure 14: Ricoh Theta S



Figure 15: Example image of Ricoh Theta S

## 2.2 Virtual Reality

Virtual reality (VR) is a computer technology that allows users to interact with a computer-simulated environment (Burdea, G. and P. Coffet, 2003). It uses multi-projected environments to create realistic sensations (e.g. imagery, sounds etc.) that simulate a user's physical presence in a virtual or imaginary environment. A user of virtual reality equipment is able to "look around" the artificial world, move around, and possibly interact with virtual features or items.

The basis of virtual reality as it appears today was formed in the late 1960s and 1970s, with the first head-mounted displays (Sutherland, 1965), however it was only in the mid-1980s that multiple special VR technologies converged to create comprehensive VR systems. A 3D virtual workspace in which the user could interact with and manipulate 3D graphical objects with hand gestures was developed by MIT (Scmandt, 1983), while NASA was working on the VIVED (Virtual Visual Environment Display) and then VIEW (Virtual Interactive Environment Workstation) projects. NASA research was mainly focused on areas such as telepresence control

and large-scaled information systems management and was aimed at creating a multipurpose, multimodal operator interface to facilitate natural interaction with complex operational tasks and to augment operator awareness of large-scale autonomous integrated systems (Fisher, 1986). Virtual reality was not introduced to the general public until 1989, when VPL Research and Autodesk both offered devices and head-mounted displays for interacting with virtual worlds. Since then, research on multiple VR areas have led to the development of VR applications and tools that can be used in many different sectors, such as medicine, chemistry, scientific visualization, etc., and add not only theoretical value but also practical effectiveness (Balaguer, 1996).

The virtual reality technology has spread to the photography world, with VR Photography being an increasingly popular subfield. It is defined as the interactive viewing of wide-angle panoramic photos or videos, usually covering a 360° circle or a spherical view (Mohammad Hafiz Ismail, 2009). It encompasses capturing or creating, with the help of appropriate software, a broad vista as a single image, as viewed when rotating around a certain position. An immersive panoramic photo is one that is exhibited in a way that lets users interact with the surrounding views.

The evolution of virtual reality photography is the relatively new technology of virtual tours that is outlined in the following pages.

### 3. Virtual Tours

A virtual tour is a simulation of an existing area, usually composed of a sequence of still images or videos, showing the geometrical properties of the location, and supplying information via multimedia, giving users a wrap-around feeling and the impression they are navigating locations and experiencing them in real time (Colasante Meg, 2011). In using techniques and characteristics that accurately represent a location, namely the exact depiction of all entities (e.g. buildings, objects, facilities, etc.), the precise layout, and a high level of interactivity with the user to control and freely navigate in the virtual environment, a virtual tour can manage to provide the user with an experience similar to visiting the real location.

Virtual tours give users the feeling of being in a location, anywhere in the world, without physically visiting it, and allow them to virtually interact with space and discover details with a simple click of a mouse. 360° panoramic applications let users navigate in any direction, view a full circle of a location and move about by clicking on hotspots created by the developer. The connection of images between them, allows the navigation of the full area within the app, while the floor plan creates a user-friendly environment, easy to navigate in.

While virtual tours can be utilised just as an innovative technique that allows people to visit places remotely in a digital environment, namely web and mobile applications, they can also be used to publicize facilities through engaging interactive experience. For that reason, they are becoming a significant online tool in many industries where the remote factor plays a big role and where location promotion is important. The industries that can most benefit from this new technology are the tourism and culture industries, universities, as well as the real estate sector.

The NTUA virtual campus tour application was created after thorough research on the most successful virtual tours, namely Google Street View and Microsoft StreetSide View, and other similar applications developed by museums, educational institutions, real estate agencies, in order to get ideas and improve on them, incorporate the most important tools and create an even more user-friendly interface.

### 3.1 Major Virtual Tour Applications

#### 3.1.1 Google Street View

Google Street View (Figure 16) is an innovative Virtual Tour application that was launched by Google on May 2007, can be found in both Google Maps and Google Earth, and provides 360° horizontal and 290° vertical panorama street level views of the surrounding area of a certain spot from a pedestrian or driver standpoint (Carrie Ann Skinner, 2008). Photos were captured by mounting camera equipment on either ordinary cars or Trikes (three-wheeled bicycles) depending on the accessibility of each location. Cameras were connected with special GPS equipment that allowed Google to keep track of image to location connection.

The application has a user-friendly interface that allows users to easily control their direction and movement speed using either a trackpad, a mouse or the arrow keys of the interface. They can zoom or pan at any desired area, change perspectives by dragging on the panorama view, and be transferred to other sites by clicking on hotspots embedded in the picture. Moreover, users can move from one point to another, or use a map view to surpass areas and move to different places fast by dropping an icon and setting the position to a certain point in the map. This facilitates the navigation around any locality. Finally, users are permitted to interact with the tool by customizing their view by selecting features that they wish to see on the map, deciding what happens when something is clicked and what gestures can be used on the map.

Since its launch, this app has been used as a base tool by many organizations and local authorities for various types of supplemental applications and tools, and while it has generally received positive reviews and praises for its useful service, there have been some complaints over privacy issues. Despite all this, Google's long-term plans involve delivering a complete coverage of any locality around the world.



Figure 16: Example of Google Street View

### 3.1.2 Bing Maps StreetSide

Microsoft in collaboration with Bing Maps have built another virtual tour application, StreetSide, which permits users to navigate in virtual panorama imagery from map locations (Figure 17). Launched in December 2009, and with a similar user interface as the one developed by Google, this app also works with panoramic transitions from one standpoint to the next, a useful feature which allows users to choose how to go about with their navigation.

StreetSide functions in a very limited area, mainly some cities in the U.S., Canada and North Europe, for which it offers virtual walk-throughs, allowing users to pan in any direction, providing information pop-ups for assistance and a bird's eye map, which can prove very useful when combined with the 360° panorama one.



Figure 17: Example of Bing Maps StreetSide

### 3.2 Software to Create Virtual Tours

Various panorama and virtual tour building software products can be used to create media rich virtual tours. There are many web-based solutions that allow users to upload JPEG spherical or cylindrical images and create High Definition virtual tours. After thorough research, the web-based Marzipano software was selected for the creation of the NTUA virtual campus tour application, as it was considered the most

suitable and flexible for our needs. Some of the most important tools and their features, including a brief introduction to Marzipano, are described below.

### 3.2.1 Marzipano

Marzipano is the tool that was used for NTUA virtual campus tour application. It is an online, free open source tool, with a straightforward interface, where the uploading of up to 50 photographs is permitted, and so tools are provided for the generation of a web application tour. Marzipano was originally created for WebGL, but can also be used on devices and browsers that do not support this system. It provides a powerful JavaScript API, which allows users to control their operations. Marzipano is compatible with modern technologies and standards, so that anyone with knowledge of CSS, HTML or JavaScript can download the code and customize it according to his needs. This flexible character is the reason why it was chosen for the creation of the campus tour application (Figure 18).



Figure 18: Example of Marzipano Tool

### 3.2.2 Paneek

Paneek is an online, virtual tour creation tool. Users are able to upload 360° images, create tours and then publish and share them online, without limitations to the number of pictures or tours created. They can add information spots as hotspots for easier navigation between them. There is a free version of the software, with all the above features, however it includes a number of advertisements on the produced tour, a limit to how many times the tour can be loaded, and some additional features are disabled. Another setback is that Paneek is not open-source- the code and the data used to build the application are stored internally in the Paneek server and cannot be downloaded to be manipulated (Figure 19).

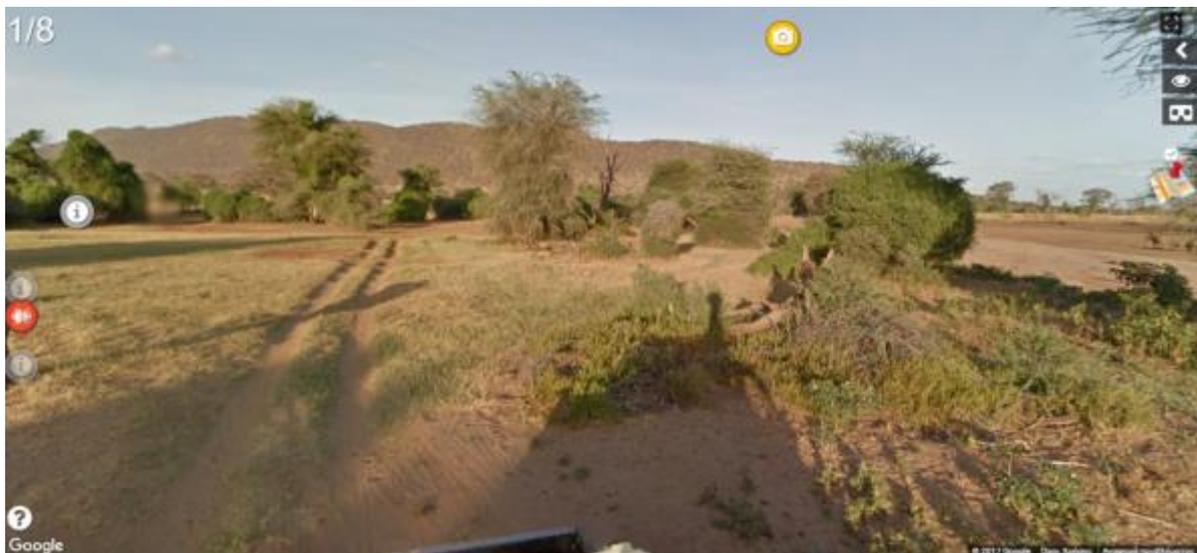


Figure 19: Example of Paneek

### 3.2.3 3DVista

3DVista is a powerful set of software that offers a virtual tour suite, a floor plan maker and a photo stitching tool too. The virtual tour suite comes at a standard edition (200 euros), which allows a user to create a very basic virtual tour, and a professional edition (500 euros), which includes many additional useful tools such as Live Pano, Hotspots, Auto-Pilot, Video, Photo Albums, Floor Plans, and Immersive Audio, for the creation of highly interactive tours. As it is not open-source and therefore inflexible to work with, 3DVista was not selected for the NTUA virtual tour development (Figure 20).

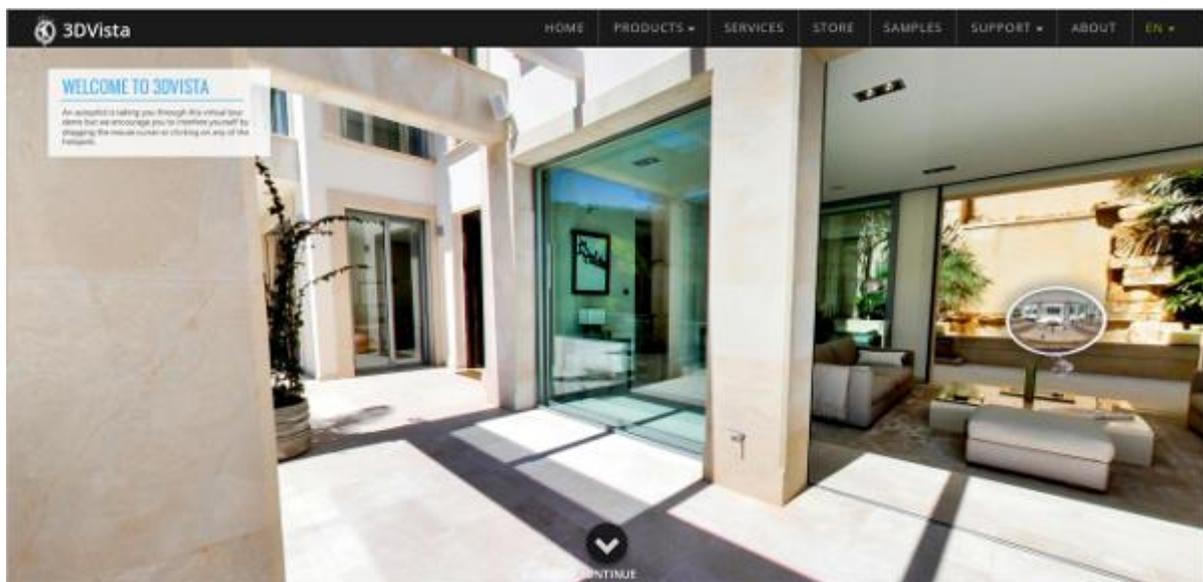


Figure 20: Example of 3DVista

### 3.2.4 Kolor Panotour

Kolor offers a comprehensive range of software tools for photo-stitching and panorama creation, virtual tour creation, and video-stitching and 360° videos creation. Its virtual tour creation tool, called Panotour, is a cross-platform panoramic imagery solution with a powerful hotspot editor. It automatically creates tours with a simple drag and drop method, and allows for sphere to cube and vice versa conversions. Furthermore, it includes modular features like maps, floor plans, image galleries, video players, etc. that can be added to a virtual tour, according to each user's needs, and many personalisation tools, such as control bars and pre-sets that allows users to design their tour having the desired look and feel. Panotour was not

selected for the NTUA virtual tour development because, like the two previous tools, it is not an open-source software, therefore not as flexible as needed. The simple edition Panotour costs 100 euros, while the pro edition can cost up to 700 euros. (Figure 21)

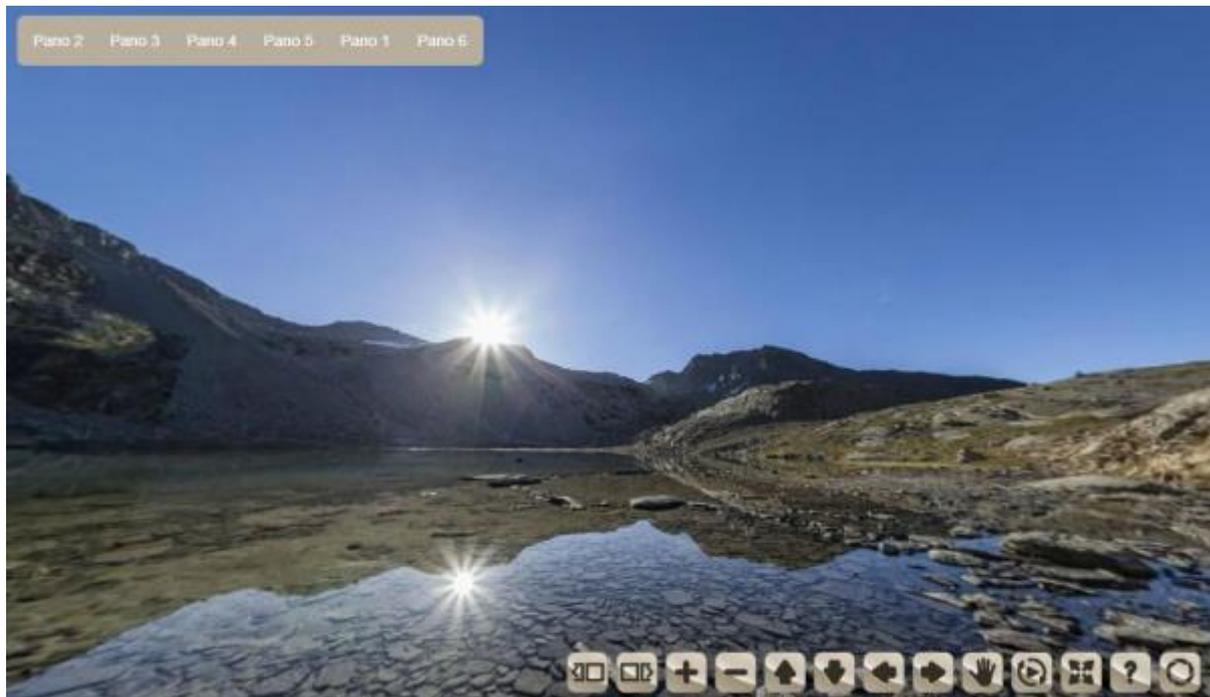


Figure 21: Example of Kolor Panotour

There are many other closed-source, paid software tools similar to 3DVista and Kolor Panotour. Some of the ones we initially considered were:

- Pano2VR, a relatively straightforward tool that contains a basic 360° video editor and allows exporting to Google Street View
- Holobuilder, a comprehensive tool that creates virtual tours in a simple manner, but contains several features that make it more complex than a typical virtual tour creator.

### 3.3 Industries where Virtual Tours can be applied to

A variety of industries use the virtual tour technology to help promote their services and product. For most business purposes, a virtual tour must be accessible from everywhere, therefore a major solution is a web-based virtual tour. Over the last few years the quality and accessibility of virtual tours has improved considerably, with some websites allowing the user to navigate the tours by clicking on maps or integrated floor plans. The main areas where this new technology is mainly applied is universities, the tourism and culture sectors and the real estate industry.

#### 3.3.1 Tourism and Culture

The virtual tour technology finds many application in various areas of the Tourism and Culture industry. Virtual tours provide travellers with valuable information regarding destinations, and help them make better decisions. When used appropriately, it is an opportunity for tourist organisations and the public sector (boroughs, municipalities, etc.) to promote facilities and destinations. In the culture sector, virtual tours allow the virtual showcase of significant exhibits from museums around the world, but also the navigation to worldwide places and locations that are otherwise unable to be accessed by the public.

- Hospitality: Hotels are gradually providing their potential customers with online tours on their websites, ranging from 360° stitched panoramas to professionally produced video tours, in an effort to better showcase their properties and other facilities and increase their profitability.
- Culture: Museums are increasingly using virtual tours on the spot, to guide visitors through exhibitions and present information tailored to their needs and interests, but also web-based remote virtual tours for users who are not able to physically visit the site.

A recent example of a museum that has dynamically incorporated new technologies for promotion purposes is the Acropolis museum, which has created a virtual tour of the Acropolis monument, allowing the exploration of the whole archaeological site in an interactive way. Additionally, it displays selected views from the ancient walls surrounding the hill, complemented with

descriptive information about the monuments and selected areas of interest. (Figure 22)



Figure 22: Virtual tour of Acropolis

- Tourist Organisations: Virtual tours are becoming very effective in displaying and promoting destinations for tourists. Several boroughs, and other tourist agencies have lately began investing in creating virtual tours to promote their municipalities, increase popularity and attract more tourists with the preview of the experience, but also aid existing ones with the inclusion of landscape and geographical conditions, tourism facilities, traffic routes, and important landmarks (Philmoon S., Yongki L., Yongbeom K., Yongju K. & Byungjip J. 2007).

### 3.3.2 Real Estate

The use of virtual tours has been increasing in the real estate industry as these applications have proven to be an excellent online marketing tool. They can take the form of a simple interactive floor plan that shows images of a property accompanied by a property map and arrows demonstrating where each image was captured, or more refined full-service virtual walk-throughs including floor plans and hotspots interconnecting spaces. This is a very effective way of accurately presenting a property and matching a potential customer with the right one (Figure 23).



Figure 23: Example of real estate virtual tour

### 3.3.3 Universities

#### *Image Gallery*

Still image galleries provide exact imagery of various buildings and locations within a campus and is one of the most common type of tours that universities utilise. It is questioned by many if this method should be included in the tour types, as these galleries do not offer much information regarding the locations of the buildings within the campus, but only a general idea of the environment. Their main purpose is to exhibit a positive view of the campus. Universities which display an image gallery in

their websites include the University of Liverpool, University of Bangor and the University of Bath (<https://www.bangor.ac.uk/>) (Figure 24).



Figure 24: Example of Bangor University, image gallery

### *Video Gallery*

Video galleries provide continuous imagery of a university campus, and are, to some extent, an improvement of still image galleries as they include much richer content and they attempt to provide some form of a campus planning. However, this type of tour still offers very limited information and imagery, and restricted user control. Moreover, videos are usually affected by the human factor (e.g. presenters, etc). Universities which showcase video galleries in their websites include the University of Nottingham, University of Portsmouth, and Kingston University (<http://www.kingston.ac.uk/>) (Figure 25).



Kingston University Statistics student Adam gives a tour of the Penrhyn Road campus: part one

Figure 25: Example of Kingston University, video gallery

### *Campus Virtual Tours*

A university's prospective students and other visitors often struggle with the layout of campus facilities, spending a lot of time trying to find their way around. Initially satellite navigation systems and later new technological advancements such as Google Maps have provided a certain solution to these problems, but it was the introduction of virtual tours, such as Google Street view, that further improved the visualization and spatial comprehension of a campus. Consequently, web-based interactive virtual tours have been getting more popular due to their usefulness, and it is becoming necessary for universities to provide such tours in order to facilitate visitors and online viewers to better grasp a campus' outline (Maines, C.L. & Tang S. 2016).

As far as interactive virtual tours are concerned, there are two types: horizontally panoramic and 360° panoramic ones. Panoramic tours provide vistas along a

horizontal axis, allowing for left and right navigation for viewing continuous images around a location. On the other hand, 360° tours provide full 360° vistas (including upward and downward navigation) similar to those of a real-world tour, offering users full control of what they view and how they interact with the map. Some minor issues still exist, such as the fact that viewers can only view an area from a certain location, from which the photograph was taken, but overall, compared with the previous types of tours, a virtual tour delivers a much better solution, allowing users to interact with the environment as opposed to merely observing it (Maines, C.L. & Tang S. 2016). Some universities that provide virtual tours of their campuses on their websites are Heriot-Watt University, University of Oxford, and Newcastle University (Figure 26).



Figure 26: Example of Newcastle University, virtual tour

## 4. The Case Study: NTUA Virtual Campus Tour

The National Technical University of Athens Campus does not so far have any kind of virtual tour, and is missing out on a big opportunity to provide its online visitors, prospective and current students, with an engaging and curated campus experience, and help them visualise themselves being a part of the campus life. The NTUA campus for which a virtual tour was created is located in the area of Zografos, in the city of Athens.

The campus takes up an area of 900,000 sq. meters fully landscaped as an organized estate that includes modern buildings equipped with classrooms, laboratories, libraries, administrative services buildings, student care facilities and other functions. The virtual tour includes the campus in its whole entirety, including only the exterior of the buildings, and a 13,000 meters long network, including roads, pedestrian streets, parking spaces and the central square (Figure 27).

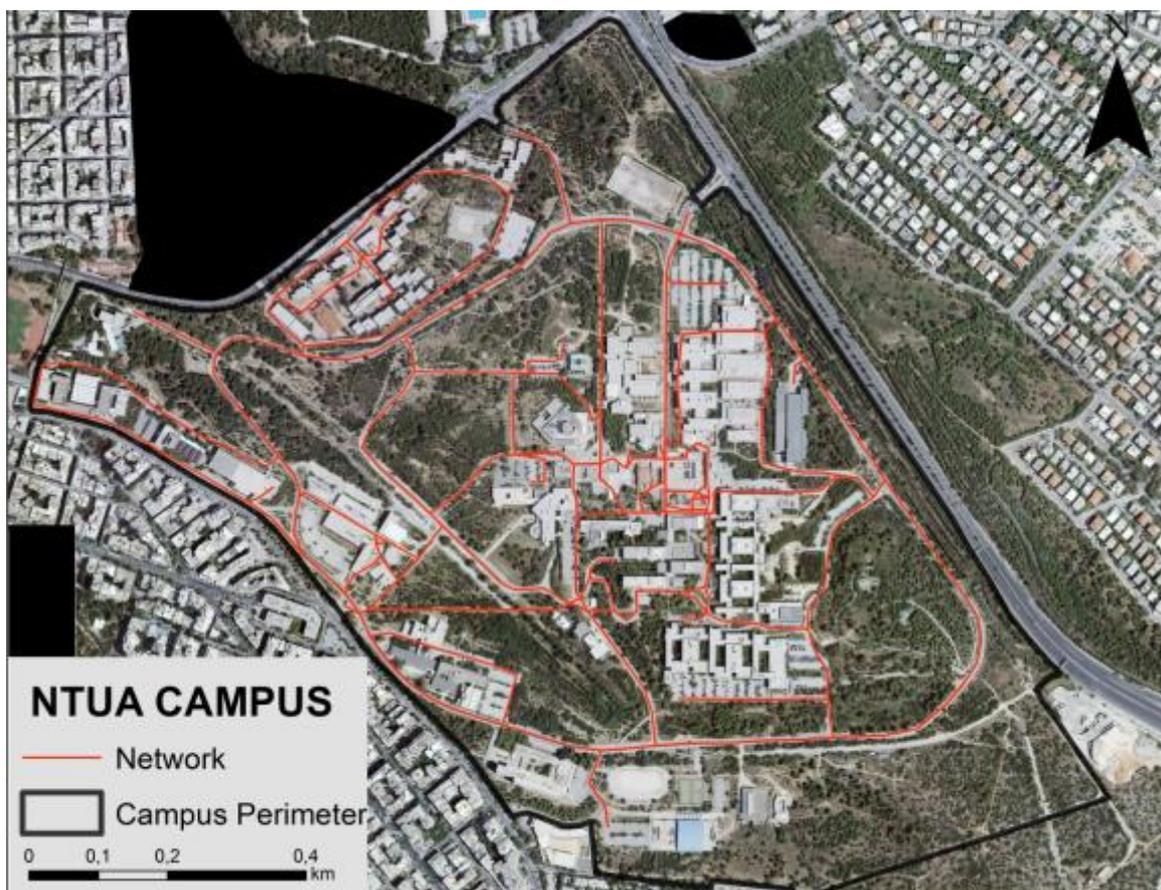
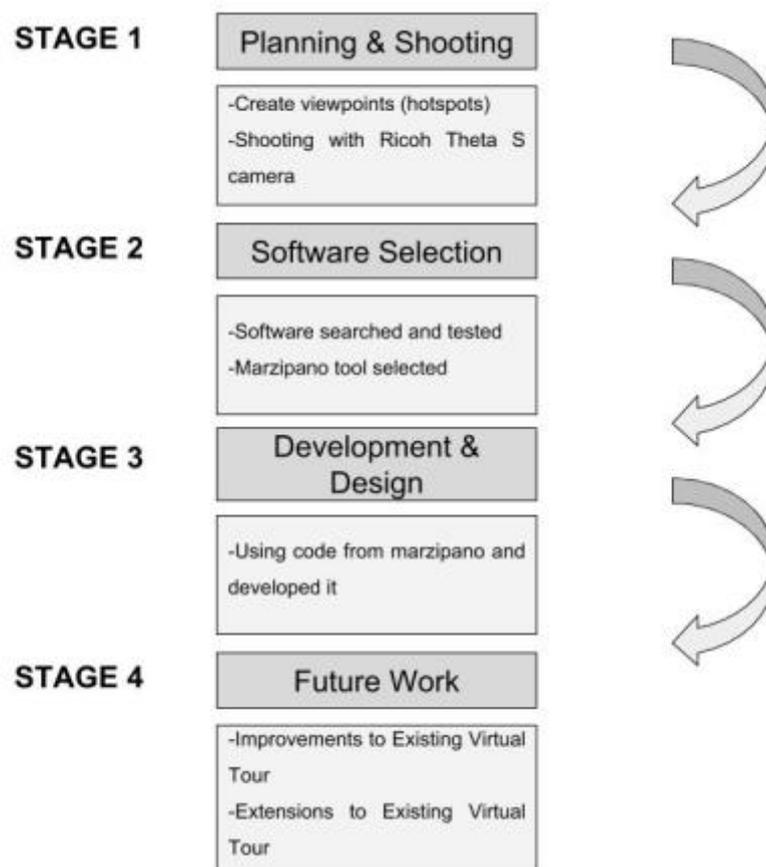


Figure 27: National Technical University of Athens Campus

The development of the NTUA Campus Virtual Tour was completed in the following stages:

1. Planning and Shooting: during this stage, the viewpoints from where the shooting would take place were determined (hotspots), the equipment which would be used for the shooting was agreed on and provided for and all other shooting details were sorted.
2. Software Selection: during this stage, many different Virtual Tour Creation tools were researched on and tested, and the most appropriate one was selected.
3. Development and Design: during this stage, the application was put together, using code downloaded from Marzipano.



Application Flowchart

## 4.1 Planning and Shooting

Initially a plan of the campus was generated to decide how many 360° photographs would be needed for the virtual tour and to determine the number of hotspots and the location of the information spots in the 13,000 meters long network. Images were captured every 20 meters around hotspots with condensed information, where there were many buildings and therefore opportunities for information spots (Figure 28). On the other hand, in areas with not much activity, images were captured every 40 meters (Figure 29). In using a 20 meters distance between shots, it was ensured that hotspots were not very far apart between them, and blind spots were avoided.

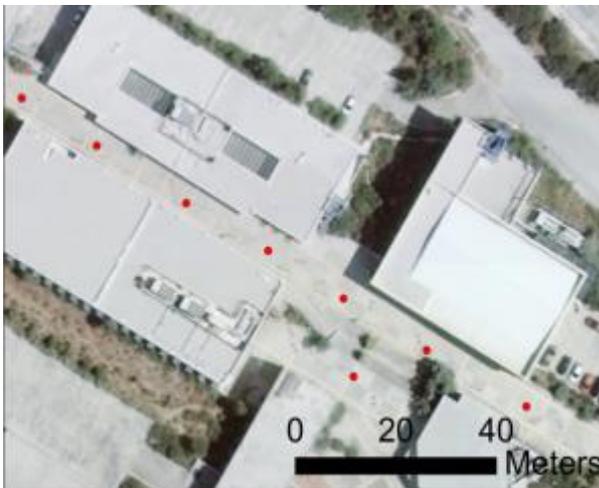


Figure 28: 20 meters



Figure 29: 40 meters

Photographs were taken with a Ricoh Theta S camera. The Ricoh Theta S is a 360° spherical digital camera. It has got two lenses and two sensors pointing in opposite directions, to capture a full 360 view (Figure 30). Furthermore, it can be connected to and operated by a smartphone via a mobile app, which shows the user a view of the camera view and allows remote controlling (Figure 31).



Figure 30: Ricoh Theta S camera



Figure 31: Ricoh Theta S mobile app

The shots were taken from eye-level viewpoints, by placing the camera on a monopod. A cardboard was placed underneath the camera, in order to cover human presence (Figure 32).



Figure 32: Cardboard

In total, 390 photos were taken, which translated to 390 hotspots across the campus (Figure 33). Because of personal data protection issues, all faces and car plates on campus needed to be covered. This was achieved by using IrfanView, a fast, compact image viewer, editor, and converter that is compatible with a wide range of image formats (Figure 34).



Figure 33: Example of photo taken



Figure 34: Coverage for personal data protection

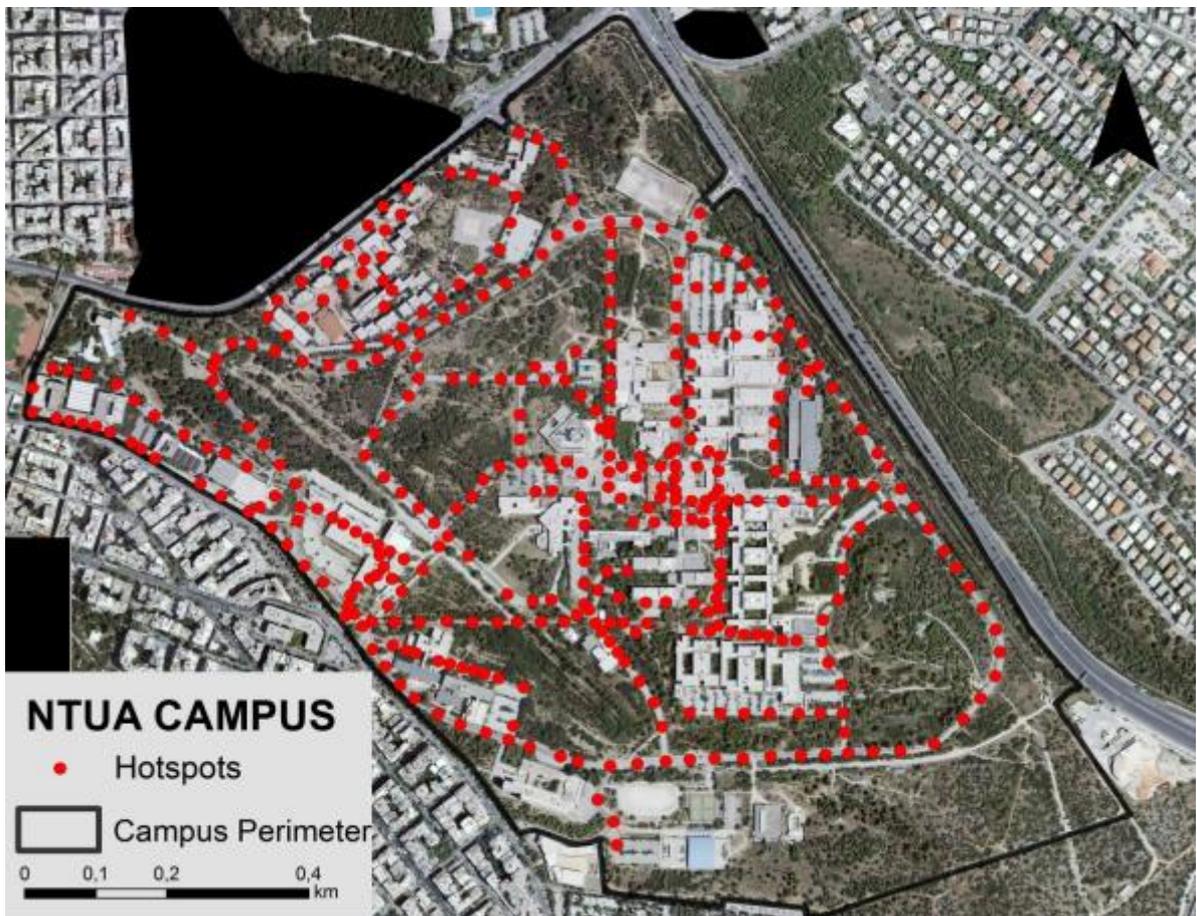


Figure 35: Hotspot map

## 4.2 Software Selection

The first step towards the development of the campus virtual tour application, was the Software Selection process, during which many different Virtual Tour Creation tools were researched on and tested, and the most appropriate one, Marzipano, was selected. Marzipano is an online, free open source tool (marzipano.net), with a straightforward interface, and includes Marzipano View, a web library to view 360° media online. It supports cube images, multiresolution cubic images, multiresolution flat images, equirectangular images and equirectangular videos.

The uploading of up to 50 photographs is permitted for each tour, and other supplementary functions are provided for the generation of such applications. Marzipano was originally created for WebGL, but can also be extended and integrated in a modern front-end development workflow, and support all major devices and browsers. It provides a powerful JavaScript API, which allows users to control their operations, and is compatible with modern technologies and standards, so that anyone with knowledge of CSS, HTML or JavaScript can download the code and customize it according to his needs. This flexible character is the reason why it was chosen for the creation of the campus tour application. As the 50 images-limit was a very big constraint, and more features needed to be implemented in the application, it was decided to download the source code and work independently.

After opening the Marzipano tool, the simple drag and drop system allows the automatic uploading of panoramic views (Figure 36).

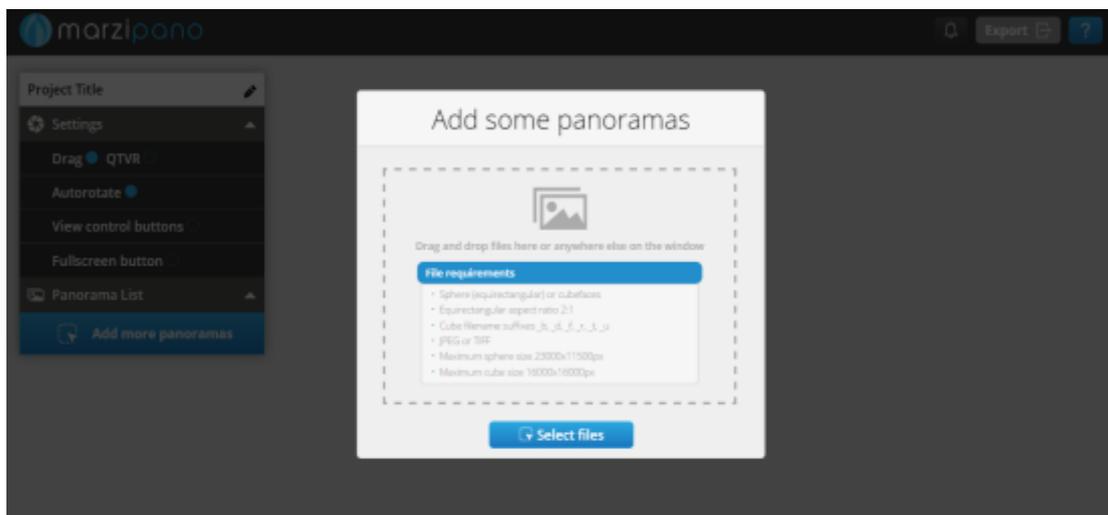


Figure 36: Adding photos

Once all panoramas were uploaded, the tool started processing them and generating cubic tiles of all different levels and then published them on the web viewer. Those tiles allowed the app to have multiple resolution levels and load only the ones required for rendering. Marzipano supports tiles in a cubic projection, which can be generated by converting each panorama into cubic view, resizing each frame into the desired resolution and slicing it into tiles (Figure 37).

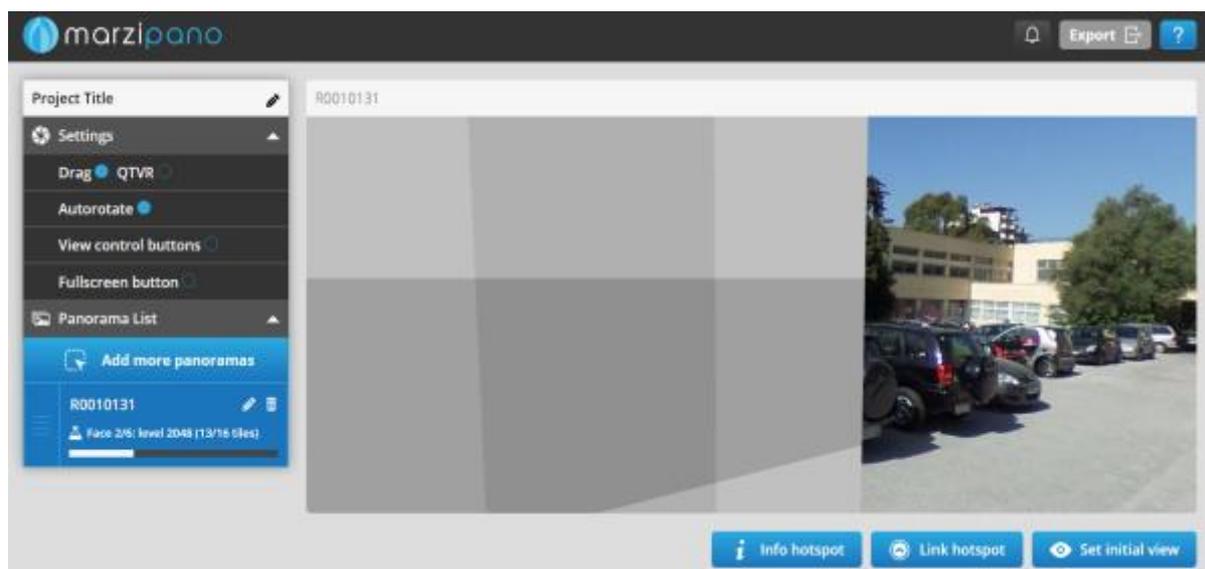


Figure 37: Cubic tiles

Panoramas were automatically uploaded and presented in the upload order in Marzipano View (Figure 38). Marzipano was then used for the transformation of spherical images to cubic ones. The new, cubic images were downloaded along with the Marzipano code, in order to be used independently for the development of our virtual tour. The following figures are screenshots of how Marzipano would work, had the application been built on the web-based tool.

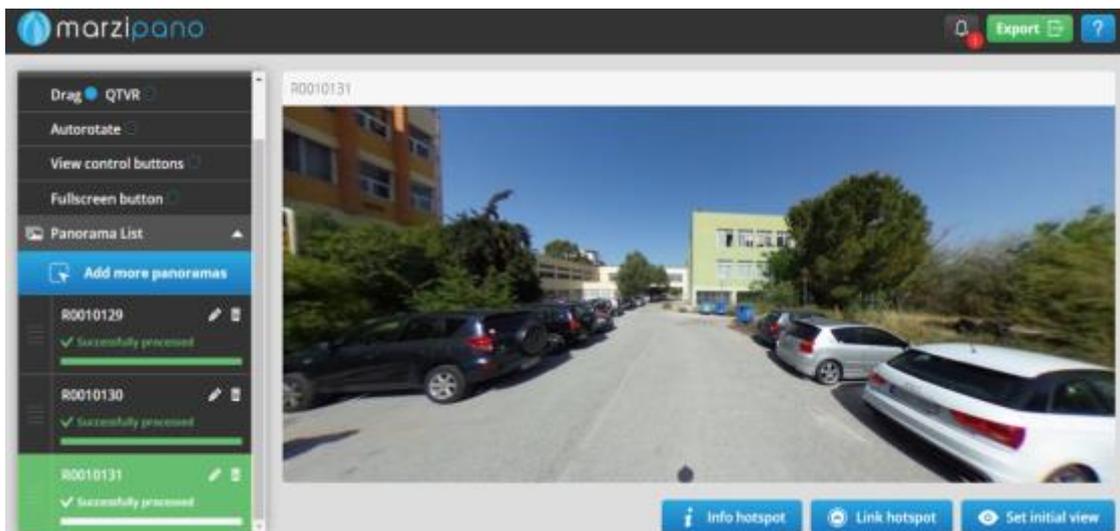


Figure 38: Managing the panoramas

After we proceeded to add information hotspots in several hotspots, to show information about buildings and other facilities. The location of the info hotspot can be changed with a simple drag (Figure 39).

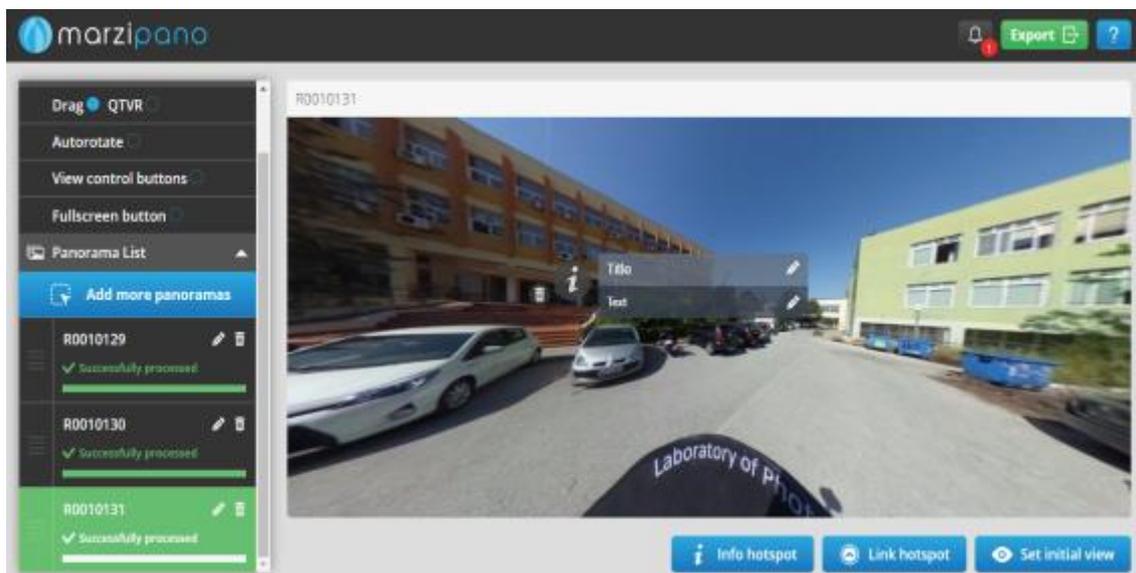


Figure 39: Adding information spots

The link hotspots (the arrows used to move from one panorama to the next), can be placed anywhere on the panoramas, simply by adding a link hotspot button, and dragging the icon to the desired spot (Figure 40).

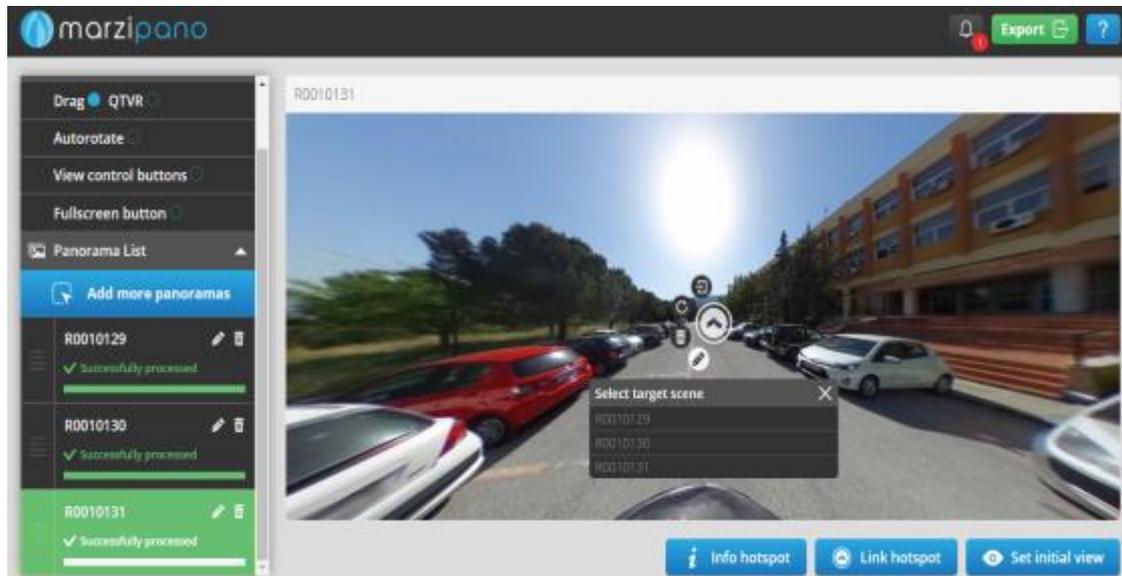


Figure 40: Adding link hotspots

When all panoramas are processed and all info and link hotspots are correctly placed, the tour, including all the files and the panoramas in a cubic form, can be downloaded by using the Export function.

### 4.3 Development and Design

As mentioned above, the NTUA Campus Virtual Tour contains 390 panoramas, way more than the 50 panoramas Marzipano allows users to input. Furthermore, small bugs of Marzipano and a number of functions that we wanted to implement to our application, which were not available in the software, led us to decide to download the code and work independently.

By repeating the code for each panorama view, and making some changes to it, the number of photos limit was overcome. A floor map was created and connected to the tour, and coordinates were set to each photo, to allow the user to move to any point on campus with a simple click of a mouse. The early code had some bugs that did not allow the user to turn at times, not to keep the right path and move in the right direction at some points, a problem that was solved by code manipulation. Moreover, some unneeded code was removed. The final application was designed and uploaded to a server. Most important changes are outlined in the figure below (Figure 41) and analysed in the following pages, including all HTML and JavaScript files created.

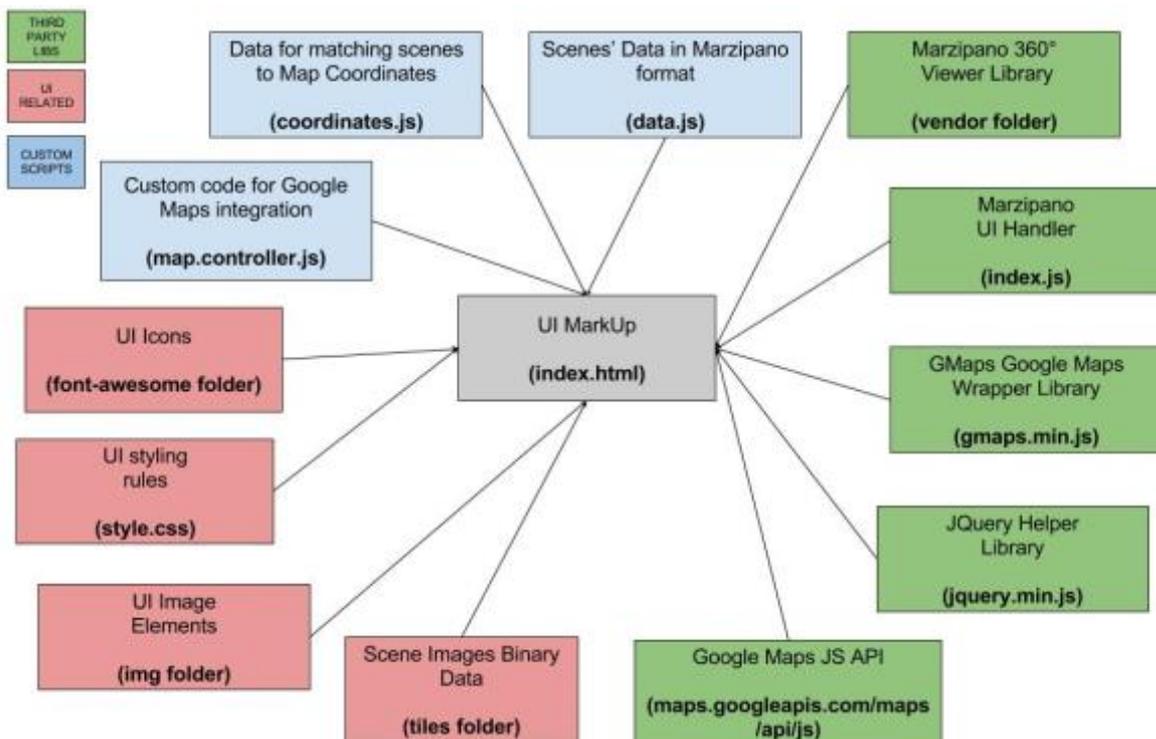


Figure 41: Virtual tour app architecture

### 4.3.1 HTML File Creation

The Marzipano application was declared as HTML5: <!DOCTYPE html>, therefore the web user interface mark up and the web page elements are located in the index.html, a file that stored all the Marzipano code so that we could work independently from the web tool.

### 4.3.2 Custom Scripts

#### *Data Functions*

The code for each 360° photo, including the photo's ID, Name, initialViewParameters, linkhotspots and infohotspots, is found on the data.js file (Figure 42). The same code was repeated for each of the 390 photos, with different inputs in each field.

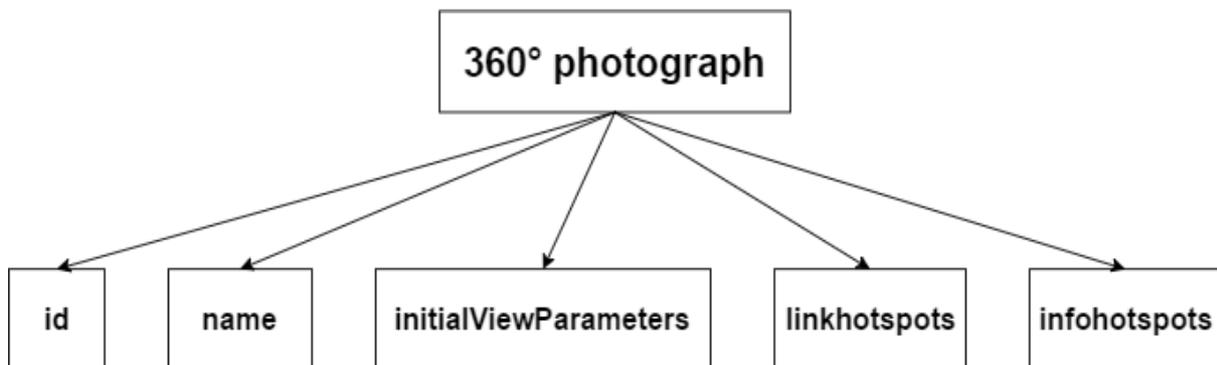


Figure 42: Photo information

```
{
  "id": "2-r0010131",
  "name": "R0010131",
  "initialViewParameters": {
    "yaw": 0,
    "pitch": 0.22086618167655736,
    "fov": 1.5707963267948966
  },
  "linkHotspots": [
    {
      "yaw": 3.1056728337593658,
      "pitch": 0.22086618167655736,
      "rotation": 0,
      "target": "1-r0010130",
      "new_scene_view_params": { "yaw": 3.1, "pitch": 0.16, "roll": 0, "fov": 0.3 }
    }
  ]
}
```

```

},
{
  "yaw": 3.1083385648926978,
  "pitch": 0.43119575858135484,
  "rotation": 3.141592653589793,
  "target": "3-r0010132",
  "new_scene_view_params": { "yaw": 3.1056728337593658, "pitch": 0.21, "roll": 0, "fov": 0.3 }},
{
  "yaw": -0.06942117899001943,
  "pitch": 0.3,
  "rotation": 3.141592653589793,
  "target": "1-r0010130",
  "new_scene_view_params": { "yaw": -0.05, "pitch": 0, "roll": 0, "fov": 0.3 }
},
{
  "yaw": -0.06942117899001943,
  "pitch": 0.1,
  "rotation": 0,
  "target": "3-r0010132",
  "new_scene_view_params": { "yaw": -0.05, "pitch": 0.11, "roll": 0, "fov": 0.3 }
}
],
"infoHotspots": [
{
  "yaw": 1.3800793581297572,
  "pitch": 3.34077092687285386,
  "title": "ΣΑΤΜ - SRSE",
  "text": "Σχολή Αγρονόμων και Τοπογράφων Μηχανικών <br/><br/>School of Rural and Surveying Engineering"
}
]
}
},

```

The initialViewParameters are the fixed parameters that Marzipano has pre-assigned to each image, and are used when opening a panorama for the first time (Figure 43).

```

"initialViewParameters": {
  "yaw": 0,
  "pitch": 0.22086618167655736,
  "fov": 1.5707963267948966
},

```

The parameters are:

yaw: the yaw angle, in the  $[-\pi, \pi]$  range. When  $\text{yaw} < 0$ , the view rotates left. When  $\text{yaw} > 0$ , the view rotates right.

pitch: the pitch angle, in the  $[-\pi, \pi]$  range. When  $\text{pitch} < 0$ , the view rotates downwards. When  $\text{pitch} > 0$ , the view rotates upwards.

fov: the horizontal field of view, in the  $[0, \pi]$  range.



Figure 43: Initial View

The link hotspots are the arrows used to direct users and guide them from one image to the next. They represent the connection between images (Figure 44).

```

"linkHotspots": [
  {
    "yaw": 3.1056728337593658,
    "pitch": 0.22086618167655736,
    "rotation": 0,
    "target": "1-r0010130",
    "new_scene_view_params": { "yaw": 3.1, "pitch": 0.16, "roll": 0, "fov": 0.3 }
  },
  {
    "yaw": 3.1083385648926978,
    "pitch": 0.43119575858135484,
    "rotation": 3.141592653589793,
    "target": "3-r0010132",
    "new_scene_view_params" { "yaw": 3.1056728337593658, "pitch": 0.21, "roll": 0, "fov": 0.3 }},
  {
    "yaw": -0.06942117899001943,
    "pitch": 0.3,
    "rotation": 3.141592653589793,
    "target": "1-r0010130",
    "new_scene_view_params": { "yaw": -0.05, "pitch": 0, "roll": 0, "fov": 0.3 }
  },
  {
    "yaw": -0.06942117899001943,
    "pitch": 0.1,
    "rotation": 0,
    "target": "3-r0010132",
    "new_scene_view_params": { "yaw": -0.05, "pitch": 0.11, "roll": 0, "fov": 0.3 }
  }
],

```

The link hotspot parameters are:

yaw: the yaw angle, in the  $[-\pi, \pi]$  range. When  $\text{yaw} < 0$ , the view rotates left. When  $\text{yaw} > 0$ , the view rotates right.

pitch: the pitch angle, in the  $[-\pi, \pi]$  range. When  $\text{pitch} < 0$ , the view rotates downwards. When  $\text{pitch} > 0$ , the view rotates upwards.

fov: the horizontal field of view, in the  $[0, \pi]$  range.

rotation: the rotation angle, in the  $[-\pi, \pi]$  range. When  $\text{rotation} < 0$ , the arrow rotates left. When  $\text{rotation} > 0$ , the arrow rotates right.

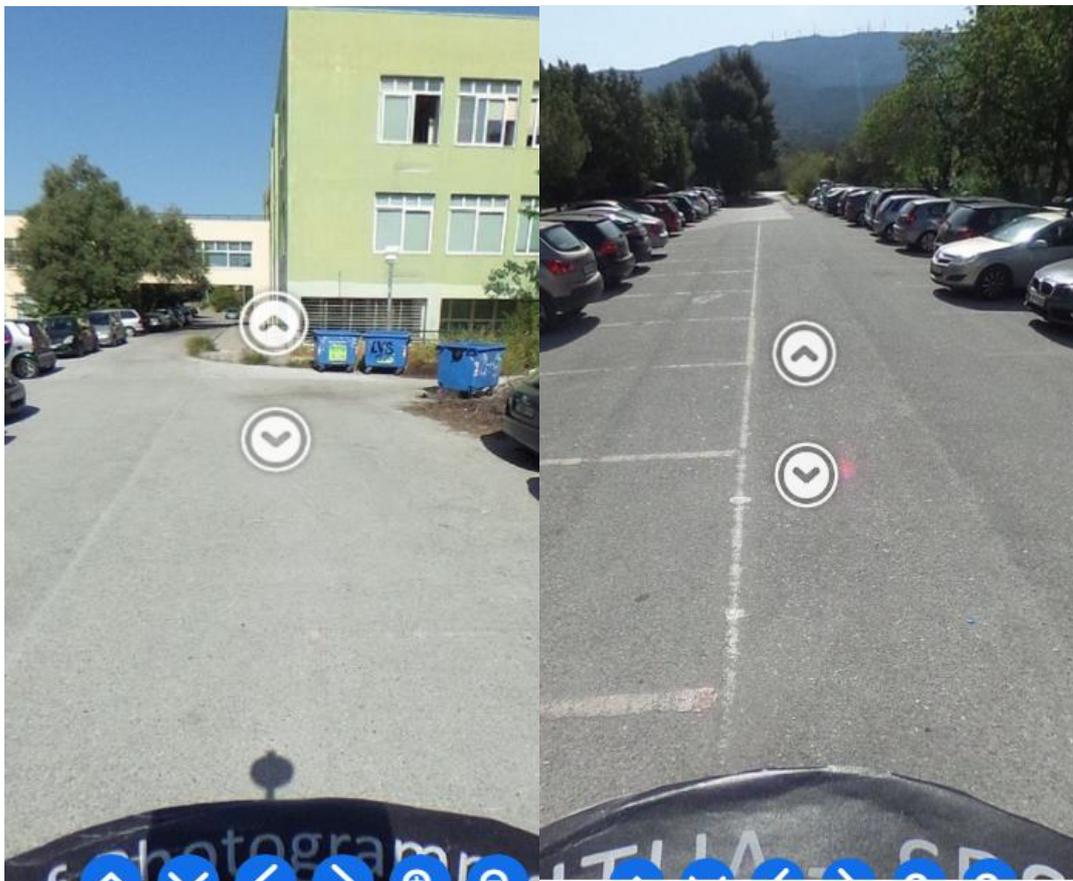


Figure 44: Link hotspots, front & back view

An important bug that we faced when working with the Marzipano tool was that in moving from one photo to the next using the link hotspots, the user was led to the new photo in a way that he faced the previous photo again. That meant that the user would have to rotate the photo by  $180^\circ$  in order to continue the virtual walk in the right direction. We wanted the photos to follow a logical order from north to south.

This was achieved by setting the view in the target scene before changing to it. The relevant code is in the `createLinkHotspotElement()` function on the index.js file:

```
// Add click event handler.
wrapper.addEventListener('click', function() {
  switchScene(findSceneById(hotspot.target));
});
```

This was modified to:

```
// Add click event handler.
wrapper.addEventListener('click', function() {
  if (hotspot.new_scene_view_params != null) {
    var scene = findSceneById(hotspot.target);
    scene.marzipanoObject.view().setParameters(hotspot.new_scene_view_params);
  }
  switchScene(findSceneById(hotspot.target));
});
```

Afterwards, the `new\_scene\_view\_params` was added to each hotspot object in data.js:

```
{
  "yaw": 3.1083385648926978,
  "pitch": 0.43119575858135484,
  "rotation": 3.141592653589793,
  "target": "3-r0010132",
  "new_scene_view_params" { "yaw": 3.1056728337593658, "pitch": 0.21, "roll": 0, "fov": 0.3 },
}
```

Information hotspots are the points where we have added additional information regarding buildings, facilities, or other areas of interest (Figure 45):

```
"infoHotspots": [
  {
    "yaw": 1.3800793581297572,
    "pitch": 3.34077092687285386,
    "title": "ΣΑΤΜ - SRSE",
    "text": "Σχολή Αγρονόμων και Τοπογράφων Μηχανικών <br/><br/>School of Rural and Surveying Engineering"
  }
],
```

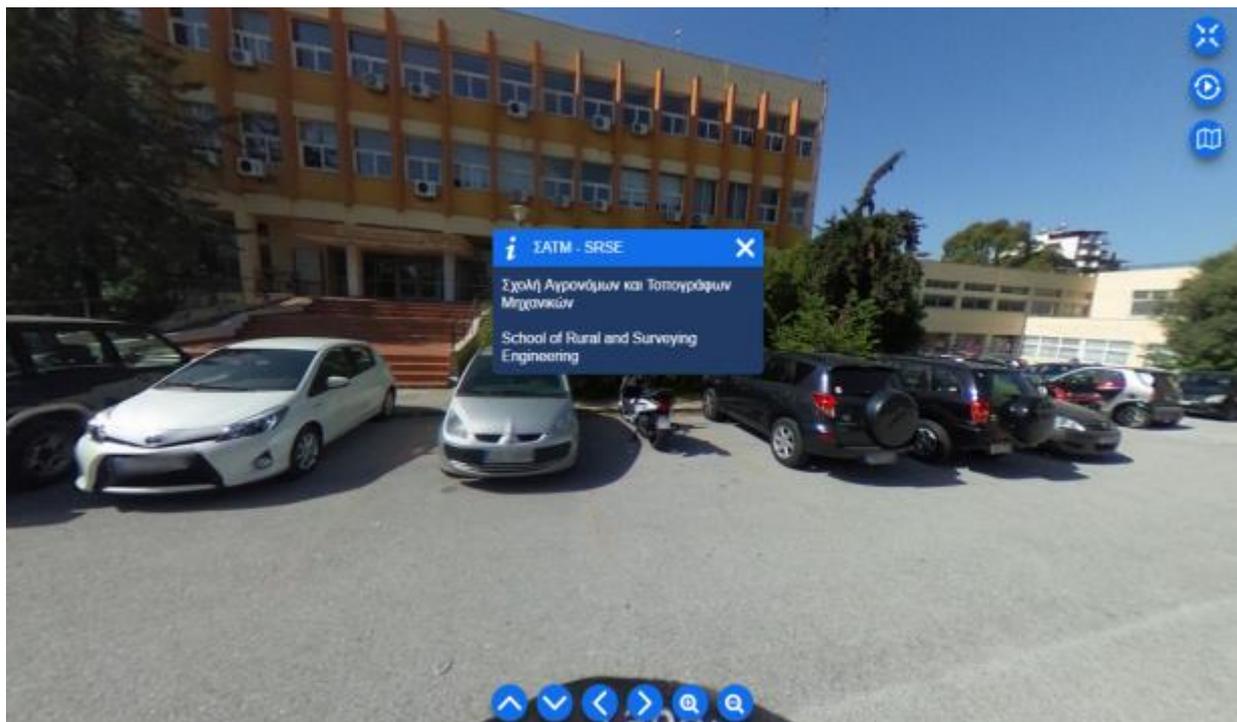


Figure 45: Information hotspot

### Map Functions

A `map.controller.js`, a JavaScript file to handle map widgets, was created. with the following functions:

initMap function

A new Google Map was created (Figure 46), along with a hide/show map button (Figure 47 & 48). This is a useful feature that helps users keep their orientation and know where they are at all times.

```

this.initMap = function() {
  this.map = new GMaps({
    div: '#MapContainer',
    lat: -12.043333,
    lng: -77.028333
  });
};

```

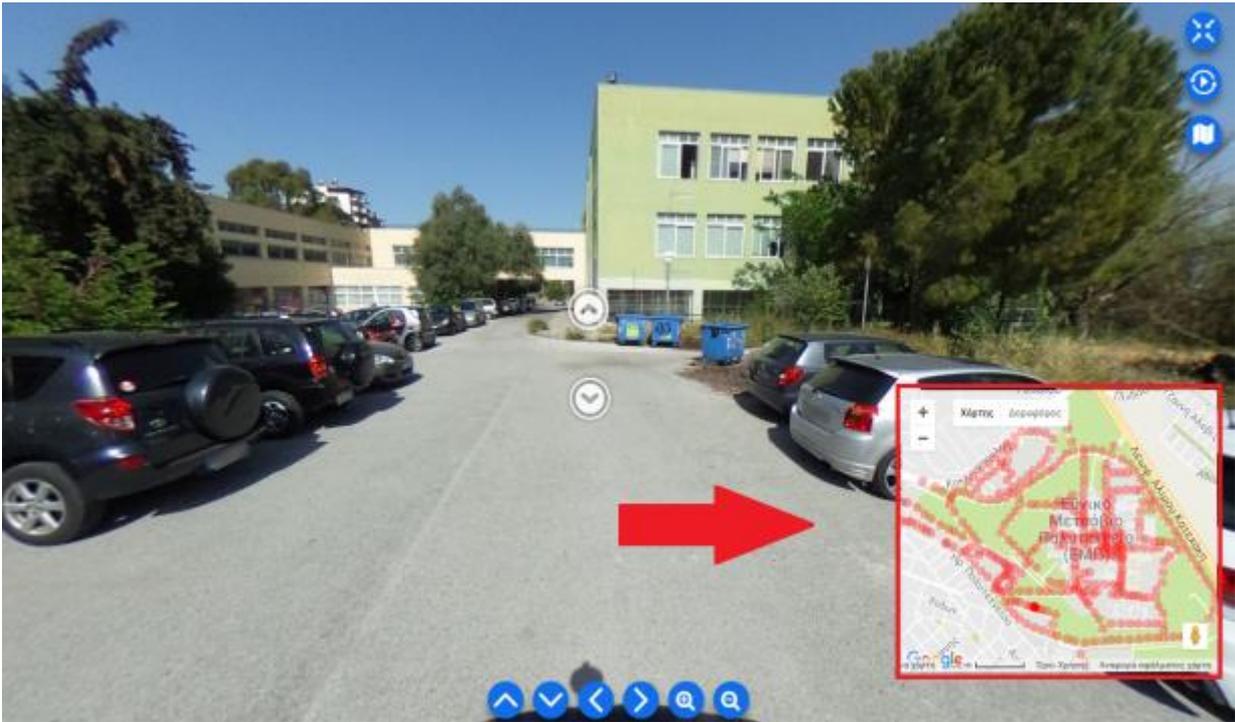


Figure 46: Map

```
$("#HideMap").on("click", function() {  
    var $this = $(this);  
  
    if ($this.hasClass("hidden")) {  
        $("#MapContainer").show();  
        $this.removeClass("hidden").addClass("visible");  
        $this.find(".fa").removeClass("fa-map-o").addClass("fa-map");  
    }  
    else {  
        $("#MapContainer").hide();  
        $this.addClass("hidden").removeClass("visible");  
        $this.find(".fa").removeClass("fa-map").addClass("fa-map-o");  
    }  
});  
}
```



Figure 47: Show map button

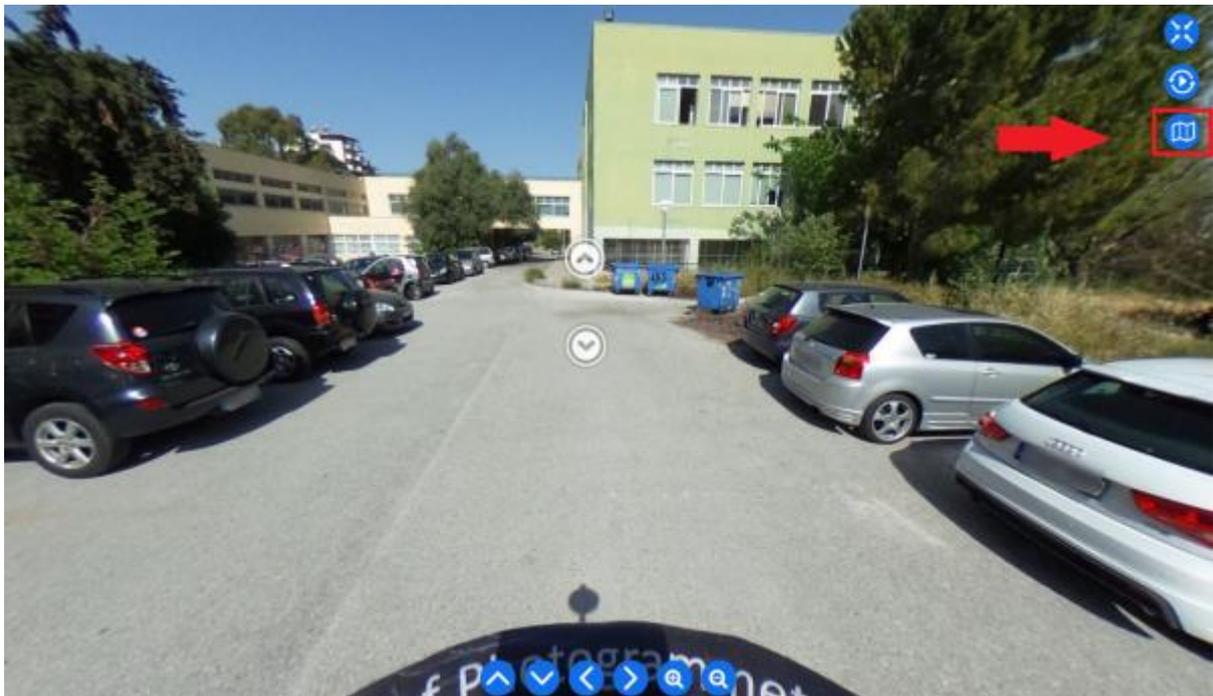


Figure 48: Hide map button

## fitToBounds

Map bounds were calculated so that the map is automatically zoomed to the level required for all markers to be displayed. This lets users have a more comprehensive visualization of the area covered in the virtual tour.

```
this.fitToBounds = function() {
    var bounds = [];

    for (var i in _scenesToCoordinates) {
        var current = _scenesToCoordinates[i];
        var latlng = new google.maps.LatLng(current[0], current[1]);
        bounds.push(latlng);
    }

    this.map.fitLatLngBounds(bounds);
}
```

## addSceneMarkers

Using data from coordinates.js stored in global variable \_scenesToCoordinates, red markers were added to the map corresponding to each hotspot.

```
this.addSceneMarkers = function() {
    for (var i in _scenesToCoordinates) {
        this.addMarker(_scenesToCoordinates[i], i);
    }
}
```

## addMarker

Using the gmaps library (third party), the red markers previously added to the map now function as automatic navigators which propel users to the corresponding hotspot (Figure 49).

```
this.addMarker = function(entry, sceneName) {
    var self = this;

    this.map.addMarker({
        lat: entry[0],
        lng: entry[1],
        opacity: 0.3,
        icon: "/img/dot.png",
        sceneName: sceneName,

        click: function(e) {
            var sceneObject = self.findSceneByName(sceneName);

            window._switchFunction(sceneObject);
        }
    });
}
```

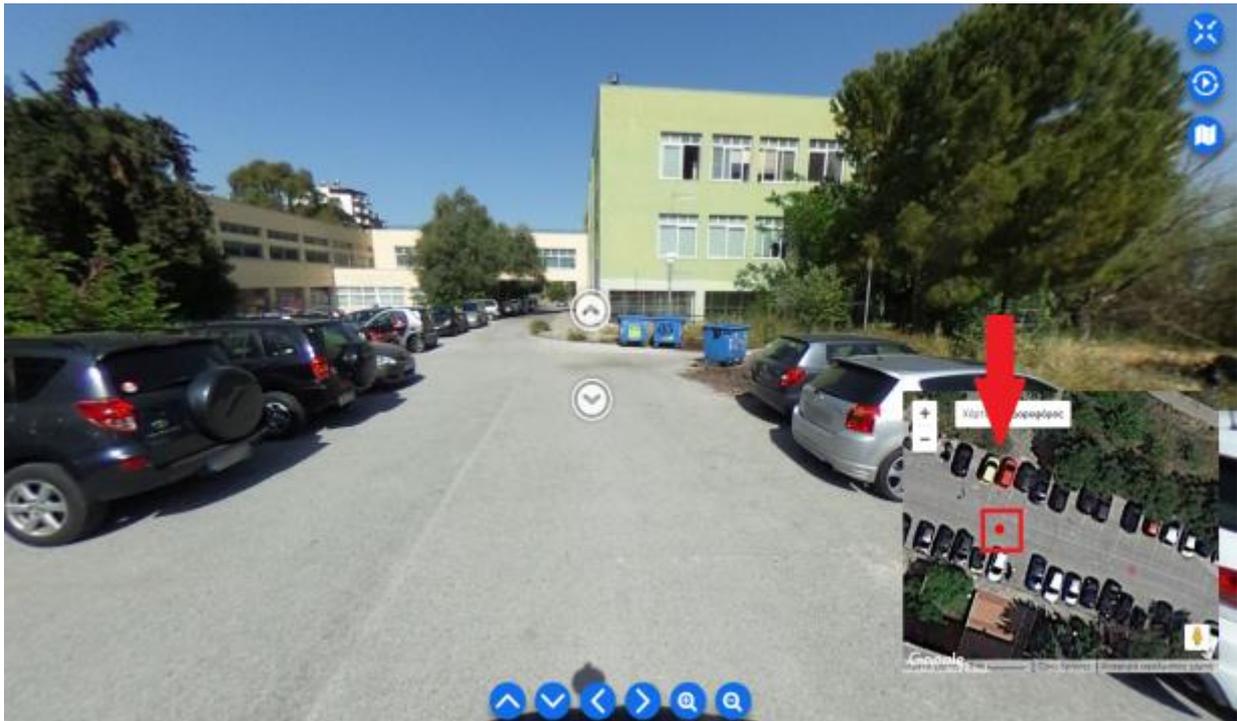


Figure 49: Hotspot marker

### findSceneByName

Scene data from data.js were searched in order to obtain scene entries by name.

```

this.findSceneByName = function(name) {
    for (var i = 0; i < window._allScenes.length; i++) {
        var current = window._allScenes[i];

        if (current.data.name == name) return current;
    }

    return null;
}

```

### updateCoordinates

Using a function (code), scene coordinates were matched to corresponding scene markers. Markers for the corresponding scene were set to full opacity, while all others were set to 0.3 opacity, in order to highlight the hotspot where the user is located.

```

this.updateCoordinates = function(scene) {
    var coords = this.findSceneCoordinates(scene);

    for (var i = 0; i < this.map.markers.length; i++) {
        var current = this.map.markers[i];
    }
}

```

```
        if (current.sceneName == scene.data.name) {
            current.setOpacity(1);
        }
        else {
            current.setOpacity(0.3);
        }
    }
}
```

### findSceneCoordinates

“Scene to coordinates” entries in the related array stored in global variable (coordinates.js) are searched for, by matching scene name and entry name.

```
this.findSceneCoordinates = function(scene) {
    var sceneName = scene.data.name;
    var coords = _scenesToCoordinates[sceneName];

    return coords;
}
```

### Coordinates

Data for matching scenes to map coordinates which are, finally, shown on our map, are located in the coordinates.js file (Figure).

```
var _scenesToCoordinates = {
    'R0010128': [37.975245, 23.780840],
    'R0010129': [37.975291, 23.780611],
    'R0010130': [37.975341, 23.780439],
    ....
}
```

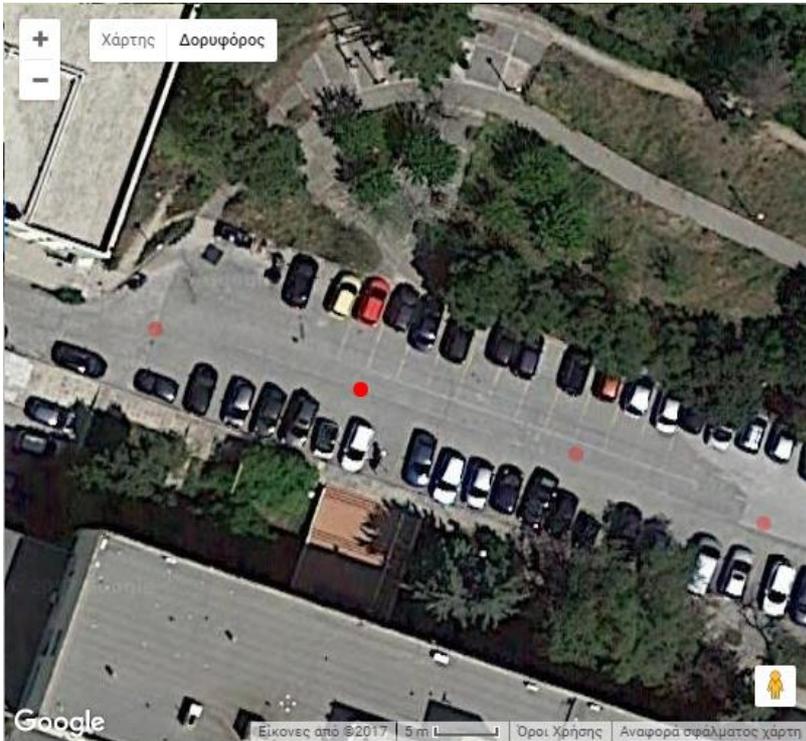


Figure 50: Markers coordinates

### 4.3.3 User Interface Design

Some user interface elements, such as the Marzipano upper tool bar (Figure 51), were removed, as it was offering information that was not considered relevant or useful for our application.

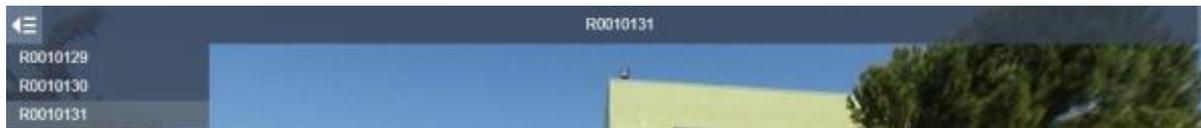


Figure 51: Marzipano tool bar

```
<!-- <div id="sceneList"> -->
<!-- <ul class="scenes"> -->
  <!-- <a href="#" class="scene" data-id="0-r0010129"> -->
    <!-- <li class="text">R0010129</li> -->
    <!-- </a> -->
  <!-- <a href="#" class="scene" data-id="1-r0010130"> -->
    <!-- <li class="text">R0010130</li> -->
    <!-- </a> -->
  <!-- <a href="#" class="scene" data-id="2-r0010131"> -->
    <!-- <li class="text">R0010131</li> -->
    <!-- </a> -->
  <!-- <a href="#" class="scene" data-id="3-r0010132"> -->
    <!-- <li class="text">R0010132</li> -->
    <!-- </a> -->
  <!-- </ul> -->
<!-- </div> -->
```

The font of lower toolbar was modified.

```
<link rel="stylesheet" href="font-awesome/css/font-awesome.min.css">
```

A hide map button was added.

```
<a href="#" id="HideMap" class="viewControlButton right-controls control-3">
  <i class="fa fa-map"></i>
</a>
```

Some user interface elements, such as a map, were added, using a div element named "MapContainer".

```
<div id="MapContainer">
</div>
```

The same procedure was followed in order for a LoaderContainer to be added (Figure 52).

```
<div id="LoaderContainer">
  <div class="loader"></div>
  <h1> Virtual Campus Tour of <br/><br/> National Technical University of Athens <br/><br/><br/> Loading
  Images, please wait!</h1>
</div>
```

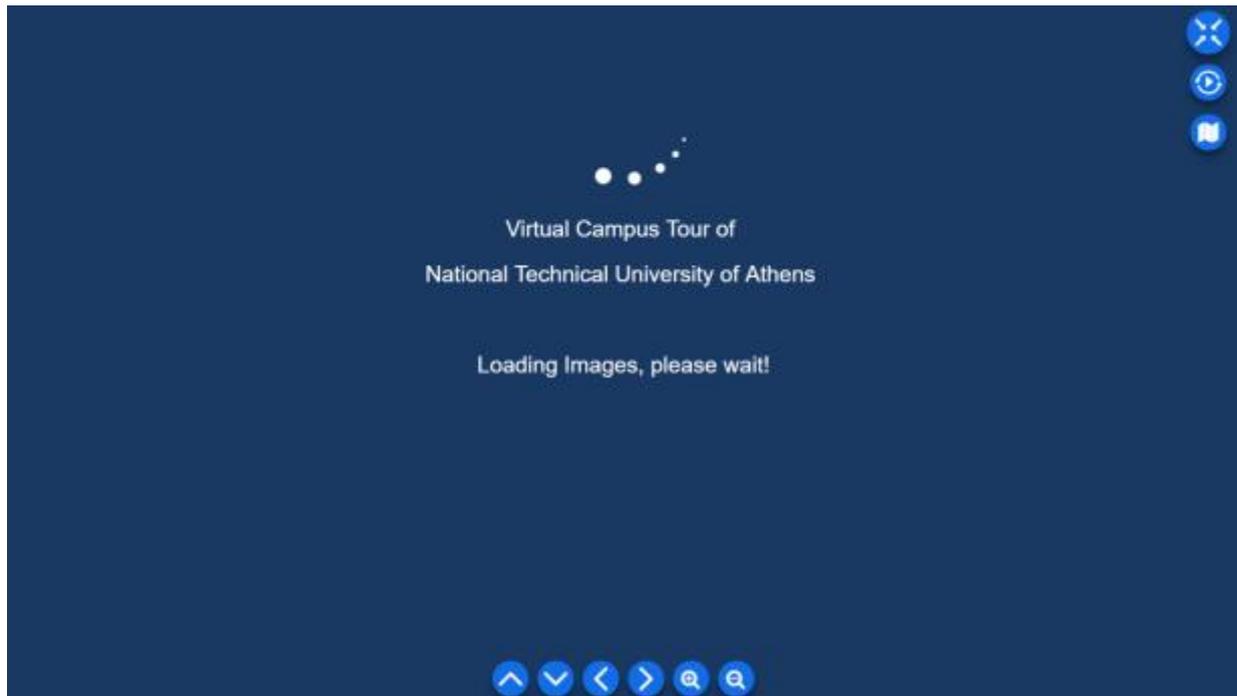


Figure 52: Loader container

References to our custom scripts were added.

The integrity and crossorigin attributes are usually used for Subresource Integrity (SRI) checking. This allows browsers to ensure that resources hosted on third-party servers have not been tampered with. Use of SRI is recommended as a best-practice whenever libraries are loaded from a third-party source.

```
<script
src="https://code.jquery.com/jquery-3.2.1.min.js"
integrity="sha256-hwg4gsxgFZhOsEEamdOYGBf13FyQuiTwlAQgxVSNgt4="
crossorigin="anonymous"></script>
```

Google Maps JavaScript API was loaded

```
<script src="https://maps.googleapis.com/maps/api/js"></script>
```

A third-party library for interacting with google maps was added

```
<script src="gmaps.min.js"></script>
```

A script for our coordinates was added

```
<script src="coordinates.js"></script>
```

A script for handling Map Widget was added

```

<script src="map.controller.js"></script>
<script>
  var _mapController = new MapController();
  _mapController.initMap();
  _mapController.addSceneMarkers();
  _mapController.fitToBounds();
</script>

```

#### 4.3.4 Third Party Libraries

##### *index.js*

The index.js contains a script for handling web user interface functions, in which:

loading screen hide timeout was added

```

setTimeout(function() {
  $("#LoaderContainer").fadeOut();
}, 15000);

```

some unneeded functions were removed

```

// Set handler for scene list toggle.
//sceneListToggleElement.addEventListener('click', toggleSceneList);

// Start with the scene list open on desktop.
// if (!document.body.classList.contains('mobile')) {
//   showSceneList();
// }

// Set handler for scene switch.
// scenes.forEach(function(scene) {
//   var el = document.querySelector("#sceneList .scene[data-id=" + scene.data.id + "]);
//   el.addEventListener('click', function() {
//     switchScene(scene);
//     // On mobile, hide scene list after selecting a scene.
//     if (document.body.classList.contains('mobile')) {
//       hideSceneList();
//     }
//   });
// });

```

Global variables (allScenes, activescenes, switchFnction, viewer) were added, so that our map controller has access to them

```

var _activeScene = null;
var _switchFunction = null;
var _allScenes = null;
var _viewer = null;

```

switchScene function was modified so that global variable \_activeScene is kept updated and map.controller handles the coordinates update

```
function switchScene(scene) {
  stopAutorotate();
  scene.marzipanoObject.switchTo();
  startAutorotate();
  updateSceneName(scene);
  updateSceneList(scene);
  window._activeScene = scene;
  window._mapController.updateCoordinates(scene);
}
window._switchFunction = switchScene;
```

## 5. Conclusions and Future Work

This chapter discusses this project's findings and contributions, points out some of the applications' limitations, and outlines directions for future research.

### 5.1 Conclusions

The aim of this dissertation was to evaluate some aspects of virtual reality technology, especially the virtual tour technology, and to analyse the development of a web-based virtual tour for the campus of National Technical University of Athens. The purpose of this virtual tour application was for users-visitors to have the ability to easily navigate anywhere within the campus, and get information about the most important campus spots.

The first section of the dissertation was occupied with a small history of panoramas, the types of cameras and ways for shooting vistas, and an introduction to virtual reality. The second section offered a more thorough analysis of virtual tours. Various software tools for creating virtual tours were assessed, and major virtual tour applications were described. Furthermore, we discussed the many functions of virtual tours in various industries, and gave an appreciation of their potential value in marketing universities and their campuses.

The final section was engaged with explaining the design and development of the case study at hand, namely the National Technical University of Athens campus virtual tour, along with all the stages of the project, starting from the planning and the shooting, continuing to the research for the software selection, and concluding with the actual development process.

To conclude, a web-based virtual tour was created for the National Technical University of Athens, which provides a realistic 'walk-around' through the campus, link hotspots for quick transfer between images and info hotspots for information regarding facilities.

## 5.2 Future Work

The NTUA Campus Virtual Tour application that was developed as part of this project, offers many possibilities for further progress. It is a very useful tool that has covered a need for technological progress in the field of spatial outlining. However, many aspects of this research deserve further consideration, and there are some ideas for additional improvements and extensions

### 5.2.1 Improvements to Existing Virtual Tour

There are several improvements that can be made to the existing application.

- The display transitions that are now very abrupt, giving the impression of jumping from one hotspot to the next, can be modified to create an effect of gliding through hotspots, similar to the way that Google Street View functions.
- A compass can be incorporated to the virtual tour, connected to the map, and radars can be placed on hotspots to improve orientation.
- Keyboard navigation can be added (arrow up: next image / arrow down: previous image) and a search form can be inserted to allow users to text the name of the hotspot where they want to jump to.

### 5.2.2 Extensions to Existing Virtual Tour

There are two important extensions that would add value to the application developed.

- Campus Indoor Virtual Tour: The application developed was focused only on the outdoor campus, including only the exterior of buildings and other facilities. This can be extended to the campus' indoor spaces, including the interior of all buildings such as offices, classrooms, laboratories, etc. Similar hotspots, link hotspots and info hotspots can be added for each building; a floor plan can be created and connected to the existing map; and the indoor space virtual tours can be linked to the outdoor space ones.
- Pedestrian Navigation Network: As the NTUA Campus is mainly used by pedestrians, it would be a good idea to include to our application a pedestrian navigation network. While navigation in general is a very dynamic research

area, most research is dedicated to car navigation improvements. Creating a pedestrian network would tender many opportunities for further study in the fields of route calculations and facilities detection. ArcGIS Network Analyst extension, and especially the Dijkstra's algorithm, can be used for best route calculations on a network datasets. ESRI's Network Analyst extension, which uses a multiple-origin, multiple-destination algorithm based on Dijkstra's algorithm, can be used for closest facilities detection.

### 5.2.3 Other Future Work

In general, the marzipano software proved certainly helpful in converting spherical panoramas to cube images, and generating tiles for all different levels that were needed, as well as in providing the basic necessary code for creating a virtual tour app. After modifying and personalizing the code according to the project's needs, a next step in order to entirely detach the tour from Marzipano would be to build an application that converts panoramas into either sphere or cube projections itself.

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