MindSpaces: Art-driven adaptive outdoors and indoors design

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Abstract. MindSpaces provides solutions for creating functionally and emotionally appealing architectural designs in urban spaces. Social media services, physiological sensing devices and video cameras provide data from sensing environments. State-of-the-Art technology including VR, 3D design tools, emotion extraction, visual behaviour analysis, and textual analysis will be incorporated in MindSpaces platform for analysing data and adapting the design of spaces.

Keywords: Virtual Reality (VR), Visual Behavior Analysis, 3D reconstruction, Emotion extraction, Style transfer, Text Analysis.

1 Introduction

The design of space, on architectural and urban scales has been shown to significantly affect the emotional, cognitive wellbeing of individuals, and to influence the functionality and effectiveness of indoors and outdoors spaces in manners that have often been overlooked in the past (Bond, 2017).

In recent years, advances in cognitive science, in sensing technologies and in the arts and creative industries have been paving the way for deeper understanding of the effects of environments on individuals' wellbeing and behavior.

In MindSpaces artists, creatives and architects will work in close collaboration with technology experts, for the development of innovative solutions to promote cultural and environmental issues in outdoors urban areas, to create inspiring workspaces and pleasant ambient assisted living environments. Art will be seen as a sense-making mechanism for which artists can frame and translate information through modes of the visual, auditory, and tactile. Art facilitates embodied knowledge through the senses which can inform engineers and architects about ways of experiencing which language or mathematics cannot always formulate for the public, leading to innovated approaches to collaborative technological development. Innovative ideas will be introduced by artists and scientists. Through the close synergy of art and technology, emotionally-sensitive immersive environments in VR and physical/VR installations will be developed.

2 Pilot Use Cases (PUCs)

2.1.1 PUC1

The first pilot use case will aim to increase sensitivity and awareness towards current issues of a city and its urban context, related to the environment, culture, society and mobility. Mindspaces will try to achieve new types of social interaction and improved levels of social connectivity with the urban fabric, through the application of innovative art installations in key locations. A first location will be the area around the cultural centre of Tecla Sala in Barcelona, Spain.

2.1.2 PUC2

The second use case will address the issue of aesthetically and functionally innovative workspaces, being created today, gradually replacing previous unimaginative and sometimes unpleasant working environments. In MindSpaces artists and architects will obtain direct user feedback by these working environments, so as to be able to guide modern workplace design in possibly unexpected, art-related directions, which are more capable of enabling dynamic communication necessary within today's networked society, improving its appeal and effectiveness.

2.1.3 PUC3

The third use case is related to the creation of emotionally appealing and functional living, domestic environments for seniors. The task is the redesign and refurbishment of an existing home, aiming at making it emotionally and functionally friendly for senior users. MindSpaces will employ interactive art installations so as to integrate end users' responses and will leverage specific aesthetic features that appeal to those specific target groups, enabling the realization of aesthetically sensitive interior environments. The proposal is to work on the themes of emotional support and affective state. Indeed, if solutions can quite easily be found for practical issues affecting seniors as they are more explicit (accessibility, security, life rhythm, health…), everything related to affective deficit (solitude, loss) is less addressed.

3 Architecture of the MindSpaces System

MindSpaces leverages multimodal data from different sensing environments. Multimedia content such as images, videos and texts will be acquired from different services of the system. MindSpaces sensors include video cameras, physiological sensors and crawlers/scrapers.

Intelligent services will analyse and process raw data from sensors having as a goal to extract valuable assets. These assets will be leveraged in order to generate new insights, which will be integrated through a semantics engine into innovative and intelligent design tools aiming to enhance and enrich the creative phase of designing outdoor/indoor spaces.

The proposed and innovative system is presented in the following figure in a high-level schema. In MindSpaces, the raw data from physiological sensors, cameras and the data from the web, will be collected and analyzing aiming to provide an additional tool during the design of indoor and outdoor environments. Artists, creatives and architects will have the opportunity to leverage the analysed data from sensors to adapt and produce new innovative designs taking into consideration the feedback from people while they experience the space in VR environment. The design ideas will be integrated artistically in VR environments, which will be modified in real-time in response to physiological and environmental measurements of end users.

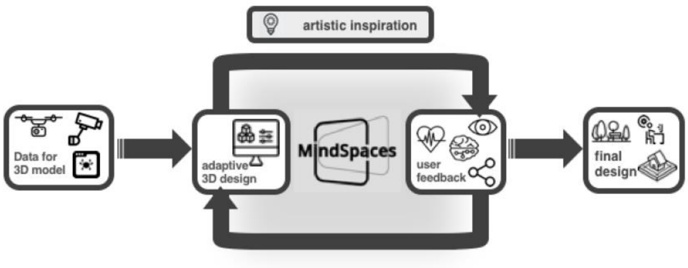

Fig. 1. MindSpaces in high-level schema.

4 Description of Modules in MindSpaces

4.1 Analysis of the offline collected data

MindSpaces platform involves the collection of offline data which are prerequisite for the creation of the knowledge base and the analysis of data from sensing environment.

4.1.1 Tools for the 3D-reconstruction of urban and indoors spaces

In this task, we will exploit image data from drones and mobile mapping platforms in order to provide high fidelity 3D models of urban and indoor spaces. The presented workflow combines custom SfM, SLAM and stereo-matching algorithms, commercial and open-source tools. Concerning the urban outdoors spaces, aerial imagery from the drone flight missions will be combined with street level images from the mobile mapping platform in order to create photorealistic 3D mesh models of high visual and geometric accuracy. For this, the drone and the mobile mapping cameras will be calibrated, all images will be oriented and dense 3D point clouds will be reconstructed with an automated Structure-From-Motion (SFM) approach. Concerning the 3D modeling of indoor spaces U2M will combine data from a terrestrial laser scanner and data from a custom-built 3D sensing platform. The workflow consists of mutual registration, mesh model creation and photo-texturing of the models via the available image data. Automatic pattern identification on images allows reconstructing both the shape and the appearance of the recorded 3D objects. In parallel to the above methodology, single image 3D reconstruction techniques that employ vanishing points and prior knowledge on objects geometry are going to be applied in paintings and 2D images, so as to build a 3D-model database that will contain interior design objects from the past. All the 3D mesh models will be provided in suitable formats for use in Virtual and Augmented Reality apps for the creation of immersive 3D experiences and in CAD/CAM software such as Rhino/Grasshopper. At the same time, the reconstructed 3D models and the captured data will be made available to the artists via the MindSpaces platform to exploit.

4.1.2 Aesthetics and style extraction from visual content

In MindSpaces project, aesthetics and style from visual content will be provided to artists to build novel 3D-artworks or spaces. In style transfer, categorized paintings will be provided to architects and artists inspiring them to create novel 3D objects. More specifically, a set of 2D images taken from the same object from different angles will be provided. Each 2D image will be processed offline and a style from a painting will be transferred. From the new set of the produced 2D images a 3D reconstruction of the object will take place, allowing to apply several different style textures from paintings and create new objects with different textures.

The challenge of style transfer has its origin from non-photorealistic rendering (Kyprianidis, Collomosse, Wang, & Isenberg, 2013), and is closely related to texture synthesis and transfer (Elad & Milanfar, 2017). (Gatys, Ecker, & Bethge, Image style transfer using convolutional neural networks, 2016) for the first time demonstrated impressive style transfer results by matching feature statistics in convolutional layers of a DNN. Recently, several improvements have been proposed. (Gatys, Ecker, Bethge, Hertzmann, & Shechtman, Controlling perceptual factors in neural style transfer, 2017) proposed ways to control the color preservation, the spatial location, and the scale of style transfer.

Fig. 2 describes the style transfer supported feature. From a content image and style reference image the goal is to create a new image which preserves the content and applies the style from a painting. The following examples are produced from a set of different methodologies described in (Huang & Belongie, 2017).

Fig. 2. Examples of style transfer results.

4.1.3 Text analysis component for the analysis of textual content from Web

The multilingual text analysis module is realized as a cascade of modular analysis stages, from text surface over intermediate linguistic structures down to conceptual structures, which can be mapped onto ontological representations for intelligent interpretation and fusion with representations provided in the context of multimedia analysis by other modules (cf., e.g., Sections 4.2.1 and 4.2.2). In particular, it contains syntactic, deep-syntactic and semantic analysis, co-reference resolution, and concept and conceptual relation extraction that are components being developed as a continuation of the research done in several European projects (Wanner, et al., 2017), (Avgerinakis, et al., 2019). Of particular relevance to MindSpaces is intelligent concept extraction based on recent advances in deep learning, which serves for the detection of entities discussed in the analyzed material. Coupled with conceptual relation extraction, it facilitates the projection of the content of the material to language-independent abstract ontological structures that are, as mentioned above, suitable for automated interpretation and fusion.

The text analysis module also contains, as an additional layer, sentiment analysis, i.e., detection of the emotional polarity expressed with respect to specific entities or their aspects in the analyzed material. The association of sentiment analysis with deep-syntactic and semantic parsing results in sentiment- and semantics-aware projections of linguistic structures into knowledge graphs necessary for deep emotional understanding. Fig. 3 illustrates a partial linguistic annotation provided by the text analysis module.

Fig. 3. Entities, emotions, and relations relevant to the urban environment use case.

4.2 Analysis for the online adaptation of spaces

4.2.1 Emotion extraction based on physiological signals

The emotion extraction service aims to develop Electroencephalographic (EEG) and physiological signal processing algorithms. These methodologies will allow the recognition of users' emotional states in the two dimensional valence arousal space and drive the adaptation of the artistic installation.

The emotion extraction service will provide means to extract users' emotional states through the analysis and processing of physiological signals, e.g. electroencephalogram (EEG), Galvanic Skin Response (GSR) and Heart Rate (HR) measurements.

EEG and physiological signals will be acquired from lightweight recording devices. The portability and non-invasiveness of these devices foster their use in users' everyday life and promote the virtual experience.

Recently, the emerging field of Graph Signal Processing, (Sandryhaila & Moura, 2014) (GSP) is applied on processing EEG and physiological signals. GSP combines traditional graph network theory with signal processing theory to analyse high dimensional signals. Graphs are generic data representation forms that are useful for describing the geometric structures of data domains in numerous applications. Recent studies have adopted GSP theory in their methods. The proposed study in (González, 2016) conducted graph analysis on EEG resting – state data in dyslexic readers.

In MindSpaces, our intention is to provide a novel emotional state extraction technique using GSP theory, validating its performance by comparing classification results from the proposed method and the conventional existing techniques.

4.2.2 Human behavior analysis from visual content

Human Behaviour Analysis (HBA) will analyze visual signals using SoA computer vision, machine learning and deep learning for the representation of human behaviour in space and time.

Video signals will be acquired from static cameras recording color video, as the non-invasiveness of these devices foster their use in users' everyday life and promote the virtual experience.

This service will provide means to extract users' behaviours through the analysis and processing of videos recording individuals and/or crowds, indoors or outdoors. A key factor of a human behaviour classification model is the feature extraction phase, often from pre-trained networks, which in the current SoA takes place via deep learning architectures (Hara, Kataoka, & Satoh, 2018), (Tran, et al., 2018) will be investigated for action recognition and classification. Action detection may also be investigated, where relevant to the use cases (Chao, et al., 2018), (Diba, et al., 2018).

4.2.3 Knowledge representation and reasoning

KB Population (KBP): The Knowledge Base (KB) population service concerns the service which maps information from multiple MindSpaces modules to the RDF-based representation format. This service includes the implementation of vocabularies that will capture: i) The aesthetics and style extracted from visual input; ii) The semantic associations and dependencies extracted from textual analysis; iii) Exterior and interior objects; iv) Cognitive and emotional data extracted from physiological sensors from end users.

Semantic Integration and Reasoning (SIR): The reasoning service will handle the further analysis of the information stored in the Knowledge base (KB).

4.2.4 Text generation

The text generation service takes structured input in terms of ontological structures, which can originate from textual analysis of the previously provided material or from non-textual sources such as the resulting structures from processing of EEG or visual signals (i.e., emotions and the visual behavior events/activities), and verbalizes the information in the language of the preference of the reader.

Due to the stratified organization of its lexical and grammatical resources being elaborated within undergoing continuous research (Shvets, Mille, & Wanner, 2018), (Mille, Belz, Bohnet, & Wanner, 2018), multilingual sentence generation provides a possibility to start from input structures of different levels of abstraction (including ontological representations). Due to their generalization-oriented modularization, the text generator can be rather easily adapted to new languages and new genres (and thus styles). This flexibility in adaptation allows us to cover all use cases in the project regarding the online adaptation of spaces both as a functional component that helps in the creative process and as a part of artistic solutions.

4.2.5 Development of semantically enhanced interactive 3D spaces

In this service, the platform will create innovative texture mappings based on the data captured by the emotion sensors in order to visualize them on the surface of the acquired 3D models. In a way similar to heat maps, the data that correspond to emotional levels and will fuel the generation of novel texture atlases for the existing 3D mesh models. Concurrently, the shape of the models will change dynamically based on the user inputs in order to adapt to the observed user reactions and produce more emotionally relevant spaces.

4.3 MindSpaces User Tools

The VR tool is developed on Unity Game Engine and uses Nuro Engine as a basis for development. The VR tool will allow the users to create adaptive environments inside virtual reality and modify environments by adding assets and 3D models coming from 3D reconstruction. The user will be able to save the scenes and other users can experience the environment created, with EEG providing the real time data of the users state of mind that can be used by MindSpaces users.

The architecture design tool, at its core, is conceived to facilitate the retrieval and visualization of assets generated by the Mindspaces platform, a set of loosely integrated and specialized applications, more as a toolkit than a single simple integrated tool. Therefore, the following three applications are conceived within the architecture design tool.

The Project Management application is designed to support the practitioner in defining and setting up a Mindspaces Project. It serves as a content management support for the practitioner, allowing to create different projects and manage the assets generated and imported under each one of them. The Project Management application is also the context in which the practitioner sets the configuration of the project and launches different analytical processes. This includes: Defining and describing the location of the project; defining the themes and select the aspects of the project from a predefined set; Importing photos and videos taken in the location; Importing documents, surveys, and other notes; Through these tasks, practitioners can seed different processes in the Mindspace platform, which in turn will develop distinct data and knowledge sets that are subsequently used in the projects, during the analysis phase as well as during the design and implementation.

The Analytics application is an elaborate dashboard conceived to visualize and analyze the data acquired in the project. Through this application, the practitioner constructs and examines the project from a data perspective, inspecting and analyzing collected and generated data to extract meaningful insights that will influence the design of solutions and artistic or architectural interventions. The Analytics application allows to cross, compare, contrast, summarize, and aggregate datasets. The Analytics application is geared towards the following concerns: Semantic analysis of the opinions mined by the practitioner; Data on human and machine flows in the designated location; Behavioral analysis of the people and participants in the location; Geolocated emotional data acquired from EEG equipment; Open data sets. The practitioner can export the data to use in other tools or as a primary material for the design, and in simulations such as VR applications. In addition, the data can also be used to empower dynamically evolving or changing solutions.

The Experimental Design application is an interactive 3D environment for designing solutions and interventions in an experimental fashion, in which the data layers and the virtualized location provide the background for integrating design components. Built on top of Rhino3D engine, this application allows the practitioner to import and visualize assets related to the solution or intervention design. In addition, several data layers are visualized over this environment to reveal behavioral and emotional patterns identified and analyzed in the Analytics application.

5 System Integration

The type of architecture model for the Mindspaces platform has to support the design, implementation, and evaluation process of artistic and architectural interventions in public, semi-public, and private environments. Accordingly, the architecture model describes a set of loosely integrated and distributed machines: a user terminal that hosts the tools and the real-time processes that run in-situ; a cloud platform for remote services and other asynchronous processes.

Therefore, the integration of the Mindspaces platform faces the prospect of connecting a heterogeneous set of modules, some oriented to user interaction, some to data processing, some to construction of digital objects, and some to the analytical modelling of different parameters. An approach has been devised in order to reduce the risks associated with the integration of relatively large set of modules with different envisioned applications, developed by different entities, and in different frameworks. The approach is composed of the following five steps: defining each module clearly in a manner that informs its classification, then after the classification, proceed to design each machine where several modules are tightly integrated. Afterwards, the deployment model, including machine-to-machine communication protocol will be developed, and finally, the final architecture design will be formulated.

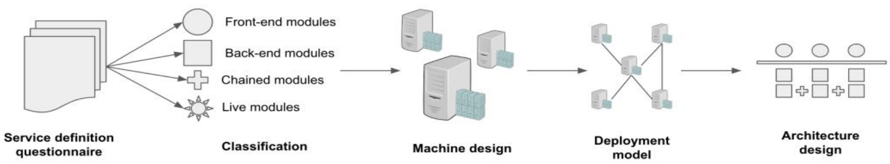

Fig. 4. Strategy for integrating the Mindspaces platform.

6 Conclusions

In MindSpaces artists, creatives and architects will collaborate to develop the solutions for adaptive and inclusive spaces that dynamically adapt to emotional, aesthetical and societal responses of end users, creating functionally and emotionally appealing architectural design in VR. A User Group, comprising groups of citizens interested in outdoors re-design efforts in their city, office employees and groups of seniors with specific design needs for their home interiors, will be created to validate the entire process. The transversal competencies and unconventional thinking of Artists, will meet the empirical and pragmatic perception of actual occupants, to drive the development of innovative, unconventional and unexpected solutions in the design of urban spaces.

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