V4Design: Intelligent analysis and integration of multimedia content for Creative Industries

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***Abstract*—Nowadays vast amounts of multimedia content is being produced, archived and digitised, resulting in great troves of data of interest. Examples include user-generated content, such as images, videos, text and audio posted by users on social media and wikis, or content provided through official publishers and distributors, such as digital libraries, organisations and online museums. This digital content can serve as a valuable source of inspiration to the creative industries, such as architecture and gaming, to produce new innovative assets or to enhance and (re-)use existing ones. However, in its current form, this content is difficult to be reused and repurposed due to the lack of appropriate solutions for its retrieval, analysis and integration into the design process. In this paper we present V4Design, a novel framework for the automatic content analysis, linking and seamless transformation of heterogeneous multimedia content to help architects and virtual reality game designers establish innovative value chains and end-user applications. By integrating and intelligently combining state-of-the-art technologies in computer vision, 3D generation, text analysis, generation and semantic integration and interlinking, V4Design provides architects and video game designers with innovative tools to draw inspiration from archive footage and documentaries, inspiring and eventually supporting the design process.**

***Index Terms*—Creative Industries, Virtual Reality, Game Design, Architecture, multimedia analysis**

I. Introduction

CREATIVE INDUSTRIES, such as architecture and gaming, are one of the most growing sectors of the economy and great sources of growth. This sector is characterised by a strong innovation capacity, able to drive innovation in other sectors of the economy, through creativity, design and new organisational processes and business models. Beyond the undoubted impact on social, democratic and cultural wealth, creative industries are increasingly being acknowledged as industrial and economic assets and their role as a driver of innovation and a catalyst for economic transformation has become increasingly important in European regional policy [1].

The creative sector is a highly competing and demanding sector, as it requires from designers to be constantly creative and multi-skilled, adapted to the latest technologies and coupled with strong presentational skills. At the same time, vast amounts of new online multimedia content is being generated and archived content is being digitised, resulting in great amounts of data of interest to the architecture and game design communities. This content is currently largely under-exploited, despite its great potential for reuse and repurpose.

As a result, it is very important to provide architects, game developers and designers of any other expertise with innovative software that will help to enhance and simplify the designing process. Most approaches mainly focus on editing or adapting existing assets, e.g. 3D models, and environments, without being able to reuse and repurpose the large amount of existing digital content in a competitive and creative manner. As such, the reuse and repurposing of digital content is mainly realised based on individual designers skills and a variety of non-interlinked heterogeneous tools.

In this paper, we present an innovative pathway to assist the creative industries in sharing content and maximise its exploitation. The V4Design (https://v4design.eu/) system enhances and simplifies the designing process by integrating technologies and tools for automatic content analysis and seamless transformation. In short, V4Design provides the ability to automatically reuse and repurpose existing visual and textual content from content providers and public web resources. It aims at exploiting state-of-the-art digital content analysis techniques to generate 3D models, extract stylistic information from paintings and videos, localise buildings and objects of interest within visual content, and integrate it with textual information so as to inspire and support the design, architecture, as well as 3D and Virtual Reality (VR) game industries. In the following sections, we firstly describe the concept of V4Design and then elaborate on the key back-end and front-end technologies that compose the proposed platform. Afterwards, we present the promising results of the evaluation based on the user satisfaction and the performance of the technical components, and lastly we conclude the

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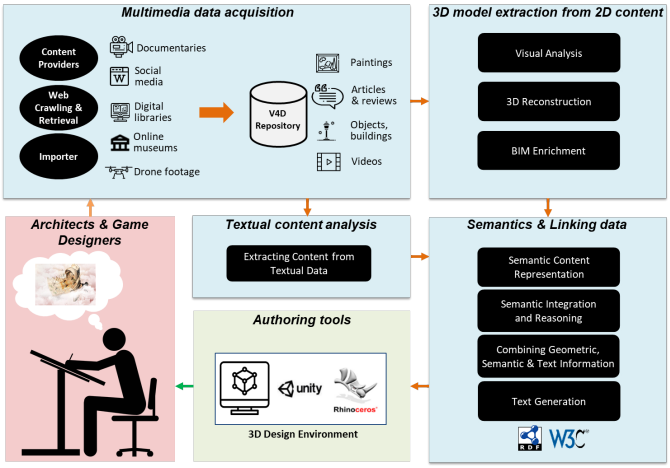

Fig. 1. The V4Design concept.

work and briefly outline the future directions towards further improvements.

II. V4Design in a Nutshell

The V4Design platform is a rich and sophisticated tool that facilitates designers throughout the whole design procedure, from the creation of an initial concept to a final design proposal. To achieve its goals, several different modules are combined and efficiently collaborating to create the content that reinforces the design process. The V4Design process is implemented as a user-oriented service, taking into account its ramifications and its different configurations. Figure 1 illustrates the V4Design concept as well as the high-level architecture of the conceived system.

The processing pipeline starts with data acquisition. This module is dedicated to acquiring freely available multimedia data (textual and visual) from different sources, including internal sources, such as user-imported data and external sources. The textual content is fed to the text analysis module, which performs a preliminary analysis, extracting features, such as concepts and named entities, and organising the results in a manner that empowers more elaborate processing tasks that describe the extracted assets. The visual content feeds the 3D reconstruction service. It comprises the main production unit of the platform, in which assets are created and prepared for repurposing. To this end, multiple visual analysis modules recognise the principle elements (e.g. objects and buildings) in imagery data (video and still image footage) before applying video and photogrammetry techniques that intelligently generate 3D representations. Next, knowledge graphs and semantic models are employed to properly capture and interlink the information, to generate natural language descriptions and to compile the semantically enriched 3D assets that are shared with the end users.

The front-end of the V4Design platform consists of two authoring tools, one for architects and one authoring tool for virtual-reality game designers. The architecture authoring tool is based on Rhino, a 3D CAD application (https://www.rhino3d.com/) and open development platform for creating plugins and custom components. The game tool is developed on top of Unity, a real-time development platform for creating 2D and 3D multi-platform games and virtual environments (https://unity.com/developer-tools).

The integration model selected for the V4Design platform is a distributed architecture with a single centralised data storage, and a middleware that plays an important role in connecting the different services and components. This architecture allows different software to be hosted on different servers, developed under different frameworks, and serviced by different teams. The middleware includes two components: a message bus based on the Apache ActiveMQ broker engine through which all communication with and between the services is channelled; and a REST API that provides interfacing capacity for the user tools with the rest of the platform. In the following, we present more details on each individual technology.

III. Content Analysis and Interlinking

A. Data acquisition

The data collection component is a fully-fledged solution that collects online data from various web resources. It is the starting point of a processing pipeline that generates the 3D assets, which are presented in the front-end tools.

Several techniques are combined to accommodate for the different types of resources, such as web crawling, web scraping and social media search. In order to reinforce the user-driven approach and to enable dynamic initialisation of the component, V4Design platform also contains the Importer, which receives data acquisition requests from users, and is also able to download videos and image collections from the user's computer to the platform's services, to be processed as raw data.

B. Content extraction from visual data

1) Localisation and texturing: The analysis of the visual content (video/images) is handled by the Spatio-Temporal Building Localisation (STBL) and the Spatio-Temporal Object Localisation (STOL) modules based on the output of the Scene Recognition (SR) module. SR extracts information about the scene depicted in the analysed image or video (e.g. village, skyscraper, museum) and characterises the scene as "indoor" or "outdoor".

Videos or images that are characterised as "outdoor" are further analysed by the STBL module , where buildings and building façade elements (e.g., walls, doors, windows) are localised. The "indoor" videos and images are further analysed by the STOL module that detects interior objects such as table, chair, sofa, bed etc.

The Texturing component applies a style from a user selected image (such as a painting or a building of a specific architecture) onto an automatically generated 3D model's texture, thereby creating a new textured asset [2].

2) 3D Reconstruction: Automatic generation of 3D models using photogrammetry is handled by the 3D reconstruction (3DR) module [3]. Video and image files, as well as output from STOL, STBL, the shot detection and texture proposal modules provide important input to the 3DR task.

We distinguish two major workflows towards the generation of 3D assets in V4Design: a) the reconstruction of video assets, and b) the reconstruction of image collections. Since the majority of the data we process is not captured for future photogrammetric use, it is important to implement mechanisms to filter bad/unsuitable data. For the reconstruction of videos, this encompasses the shot detection and frame extraction modules. Based on sum of absolute differences (SAD) and Geometric Robust Information Criterion (GRIC) techniques, the most suitable shot and frames are automatically extracted from an input video. For the processing of image collections, a robust way of clustering images depicting the same scene is conducted with the use of a vocabulary matching strategy. Finally, the module conducts the ultimate steps of restyling the 3D model based on the outcome of the Texturing process.

C. Text analysis and generation

Content extraction from textual data is carried out by the text analysis (TA) component that analyses the textual material that is associated with or related to the assets of the platform [4]. The material originates from a variety of sources: (i) image captions and video descriptions; (ii) Wikipedia articles; and (iii) opinions conveyed in critics and reviews from the Web at different points in time.

The multilingual text generation component is based on the grammar-driven FORGe generator [5], which has been adapted to create rich textual descriptions on the assets generated by the platform. In particular, content catered by four components is verbalised: visuals analysis, text analysis, the opinion analysis and DBpedia [6]. The content reflects 45 architectural features (among them, e.g. type of landmark, style, creator, etc.) and five metadata properties. The descriptions are generated in English, Spanish, Greek and German, with different levels of coverage.

D. Semantic integration

Semantic integration enriches V4Design with a semantic annotation layer by providing the appropriate knowledge structures to represent the data and store them into the Knowledge Base. The module also offers semantic retrieval capabilities by executing semantic queries, as well as a rule-based semantic reasoning module that extracts useful inferences.

A unified model has been designed as an OWL 2 ontology (https://www.w3.org/TR/owl2-overview/), capturing V4Design information, using the Web Annotation Data Model, in order to promote interoperability and reusability [7] [8]. Existing schemata and ontologies, such as Building Topology Ontology (https://w3c-lbd-cg.github.io/bot/), have also been used to inherit useful classes and relationships. Using Linked Open Data (LOD), we assist in making richer descriptions (by serving the appropriate information to Text Generation module) and offering an intelligent conceptually based semantic search to the users (accessible through the V4Design tools).

IV. AUTHORING TOOLS

One of the key technological achievements of V4Design is the implementation of two authoring tools that exploit and integrate novel content analysis techniques to generate 3D models, extract stylistic information from paintings and videos, localise buildings and objects of interest within visual content, and integrate it with textual information.

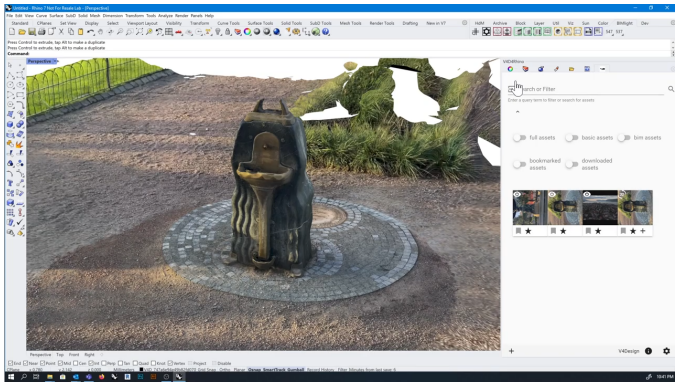

Fig. 2. Architecture authoring tool (Rhino plugin). On the left side of the figure, the UI of the Rhino Authoring tool is shown.

A. Architecture Design Tool

The Architecture Authoring tool serves as a content and process management environment through which users can access the V4Design platform and retrieve assets from its storage. It is a mature application developed on top of Rhino. It connects to the backend and implements data search, retrieval, download, import and export functions, including a seamless integration of downloaded assets with the Rhino editor. In addition, it facilitates the discovery and retrieval of 3D models for repurposing, and allows users to access raw data (shots and image clusters, with original text). The tool is published as a Rhino package and can be downloaded and installed from Rhino using the Package Manager. Figure 2 shows the architecture design environment in Rhino.

B. Game Design Tool

The Game Design tool is composed of two applications: a) the Unity plugin, b) the VR tool. Each application contributes in a different way to the fast and efficient creation of VR games and experiences.

The Unity Plugin (Figure 3) has been developed for the Unity Game Engine and enables users to download assets from V4Design repository, upload videos for reconstruction, rating assets and use a set of prefabricated gamification templates (triggerables) that encourage and allow various forms of interaction with the end users.

The VR tool enables the creation of new environments directly from inside the virtual world. It supports a subset of the functionalities of the Unity plugin and is implemented to help the developers import and place 3D models and recreate the environment on-the-go so as to enhance the final experience for the user. This application imports assets and questions from the V4Design databases and is compatible with any Steam VR compatible device, such as Oculus Rift.

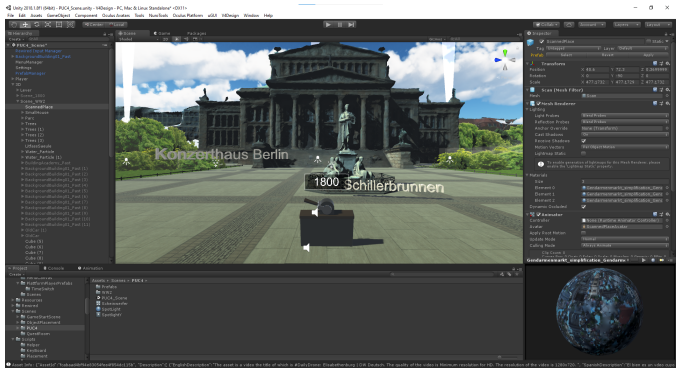

Fig. 3. Game design authoring tool (Unity plugin).

TABLE I
SUMMARY OF V4DESIGN SYSTEM EVALUATION RESULTS

effectiveness	efficiency	satisfaction
3.4	3.0	4.0

V. V4DESIGN EVALUATION

For the evaluation of the platform, three workshops have been organised. The Aristotle University of Thessaloniki (AUTH) conducted an academic evaluation based on architecture-oriented scenarios, namely the design for a historical landscape in Greece and the design of small-scale objects inspired by East Asian culture. Herzog & de Meuron (HdM) and McNeel conducted two evaluation/demonstration events for the V4Design for Rhino plugin, internal interviews and a YouTube live event. For the evaluation of the Unity plugin, Nurogames with Deutsche Welle (DW) held and open day mostly with academic users. Participants provided a valuable assessment of the platform in the game design scenarios.

The evaluation of the final system tested the effectiveness, efficiency and satisfaction of the developed final system. In particular, effectiveness is defined as the extent to which the user can fulfil a task and achieve their goals. Efficiency depends on how the effort the user needs to invest relates to the accuracy and completeness of the results. Lastly, satisfaction expresses how satisfied the user is by working with the system. It indicates whether users are pleased with the design of and their interaction with the tool.

In Table I, we present the aggregated results of the entire system evaluation. The values represent the averaged Likert scores of all the answers (from every user, where values range from 1 to 5 and 5 shows the highest degree of approval), for the set of questions belonging to each of the aforementioned evaluation metrics. Apart from the system evaluation, the users assessed the quality of specific components and functionalities, in terms of the satisfaction metric. Table II shows the mean Likert scores of the tested features.

Overall, the evaluation showed satisfactory results. Assessments indicate that the GUI and the interface of the different modules were considered as user-friendly and easy-to-use by users. Testers deemed V4Design as easier to use in comparison to its competitors and expressed that they quickly familiarised with it and are willing to use it in the future.

TABLE II
SUMMARY OF RESULTS PER COMPONENT

Component / Feature	Mean score
3D Reconstruction	3.6
Style transfer	3.4
Texture transfer	3.7
Textual summaries	3.2
Search functionalities	3.1
Create Asset-import video	3.9
Asset rating functionality	3.8
3D asset quality	3.0
Texture quality	3.4
Asset store access	3.8
Applying assets	4.0

VI. CONCLUSIONS

In this work we described V4Design, a novel platform conceived for architects and game designers that is capable of exploiting the abundance of existing multimedia content towards automatically generating 3D assets and reinforcing the design process. The creation of these assets involves a sophisticated pipeline that acquires online data, reconstructs 3D models, and develops elaborate metadata and descriptions, among other tasks. Authoring tools have been developed on top of well-known software to visualise the results and help end-users remain creative, innovative and competitive. Future advances on the underlying state-of-the-art technologies would further extend the impact of the proposed system in the creative industries.

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