Digital Twin for Everything: Some Pilot Studies
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Abstract. Digital twin for everything has been proposed as a novel idea to implement digital transformation in the 4.0 era. Beyond the industrial applications, more than 70 experimental prototype systems have been developed by the author so far to demonstrate its feasibility and general availability for applying digital twins in cultural heritage and knowledge dissemination areas. A universal methodology is developed based on knowledge-graphs and future Internet technologies to implement a goal-oriented resources integration and provide high-value cultural and knowledge cloud services, which can be co-created and shared by people, towards building an ideal cultural and knowledge ecosystem.

Application Extension of Digital Twin
Digital twin, as a virtual replica of a physical asset in the real world, has been listed by Gartner as Top 10 Strategic Technology Trends for 3 consecutive years, from 2017 to 2019 [1], and viewed as a key technology for Industry 4.0. However, current R&Ds are solely concentrating on industrial applications. For our viewpoint, more value could be created by pursuing digital twin for everything.

According to the author, the value of digital twin comes from purposely introducing the DIKW hierarchy into a dumb physical world and enabling possible IT processing to create more smart products and factories for digital transformation. Based on this perspective, we think back to the cultural and knowledge domain and can simply find there are already rich and native DIWK contents behind. The key is how to organize effectively these resources and exhibit them clearly and vividly. In turn, more valuable smart cultural/knowledge products and services can be built and rapidly disseminated at large scale over the Internet. In this sense, applying digital twin in the cultural and knowledge domain would be much simpler and easier than in the industrial domain. We will demonstrate such claim in this paper with a universal methodology plus a set of prototype applications.

Goal-Oriented Active Cultural and Knowledge Services
Human civilization and S&T advancement have brought us a historic opportunity for development that never met before. Now people are looking forward to the coming of fourth industrial revolution, even thinking about the smart economy after knowledge economy. This is really a fast changing era. More important, it coincides with a new turning point in human history while knowledge entering into the network (new media) era. Knowledge transfer is no longer rely only on paper-based manuscripts and will spreads out with a network speed. The influence and value of knowledge and culture will increase exponentially with the network size according to the Metcalfe’s law. It is hard to forecast its potential impact on progress of human civilization. What we can do just to push that new age demands new solutions. This is why we propose here a digital twin approach to promote digital transformation.

According to our viewpoints, knowledge and culture are not only a passive underground resource just waiting for mining. It can be also an active service, that is, to organize necessary resources and directly send them to who demand. We called this: “Knowledge as a Service (KaaS) and Culture as a Service (CaaS).
It will be a goal-oriented methodology, that is, based on the development objectives, identify the resources required and target digital twins to be built through requirement analysis, then design an integrated framework for organizing and presenting resources (i.e. digital modeling) to embody its service value.

The Underlying RPV Innovation Theory

A Universal methodology is proposed in this paper for building digital twins of knowledge and cultural assets, that strictly follows the RPV innovation model [2], i.e. based on the resources $R$ required by the served objective, design an appropriate building process $P$ to provide the requested service value $V$.

The goal-oriented approach ensures accurate and unique value proposition. Supported by professional services, the domain expertise can assure effective and optimized resources organization. High integration of all available resources may facilitate maximization of service value. For cultural heritage, it not just do simple copy or recurrence, but stress on discarding the dross and selecting the essential, discarding the false and retaining the true. It fully conforms to the spirit of ‘Making the ancient serve the present, innovative development’ emphasized by the National project on promotion and development of traditional Chinese culture excellence. The following figure depicts the proposed approach for building cultural digital twins:

![Figure 1. Digital Twin Building Based on RPV Innovation Theory.](image)

Resources Organization Based on Knowledge Graph

Whether a vital development objective or a valuable cultural heritage, it often consists of rich knowledge components and correlations. Therefore, for the purpose of building a corresponding digital twin, an underlying support tool is required to express the semantic implications. Undoubtedly the Google’s Knowledge Graph (KG) would be an ideal candidate tool, besides usable for smart search, which has also been widely applied by many museums abroad as a basic tool for developing smart museums.

In recent years, the KG is becoming a hot spot as the cornerstone of AI technology to be used for automatic discovering new knowledge through mining large volume of unstructured data. This can be considered as a ‘bottom-up’ reasoning approach by seeking for correlations between information entities. However, a fully automatic solution lacking of resolution always yields lot of garbage information.

When using the KGs in defining digital twin, we adopt a reverse strategy, that is, to reuse the implicit knowledge of domain experts through a ‘top-down’ approach by which the inherent semantics of the target digital twin can be explicitly elaborated by a layered knowledge graphs. This can be considered as a live summarization of object knowledge that is highly succinct and complete, due to professional services from domain experts, able to reflect the cognitive essentials of the target object without any interference from garbage information. Here the KG is equal to a knowledge modeling tool of digital twins and the defined KGs can be viewed as a digital architecture of specific object.
The main advantage of KG is its high conceptual abstraction, which is very easily to be acceptable and understood. For the developer, a complex object can be clearly and concisely decomposed by a layered KGs, moreover, which can conveniently support both horizontal dynamic expansion and vertical stepwise refinement. By introducing domain ontology, this approach can be flexibly applied to various domains as shown by our application cases later. For the user, the KG looks like an intuitive graphic menu or knowledge map, by freely navigating, he can quickly locate the spots to be interested and then by a simple click on the icon to acquire linked resources.

**Supported by Future Internet Technologies**

Digital twins in industrial domains are implemented by one key technology, i.e. the well-known IoTs (Internet of Things) unfortunately which are useless for ‘virtual concepts’ in cultural and knowledge domains. To formulate a complete organic body for digital twins in cultural and knowledge domains by connecting all related components and resources, it need to fully utilize the ‘connectivity’ power of the Internet similar to IoTs. Fortunately enough, there already has a new buzzword in the industry 4.0 era so-called “Internet of Everything - IoE”. The familiar IoTs is only one of four pillars in the future Internet technologies [3] as shown in Figure 2.

![Figure 2. Future Internet Technologies.](image)

The proposed approach to digital twin for everyone will utilize other three future Internet technologies except IoTs, they are: *Internet of Contents and Knowledge* (IoCs, IoK), *Internet by and for People* – a people-centered method i.e. co-created and shared by people, *Internet of Services*—implemented by a chain of services.

By virtue of IoCs people can directly look not only all contents and components of a cultural digital twin, but also get all linked illustrative resources for learning purpose to increase its education value.

**Digital Twin Prototypes in Cultural Domain**

To avoid a pragmatic method to stop at a mere paper talk, we have developed so far 32 prototype applications to show its feasibility and applicability as well as application value. These pilot projects can be categorized into various types as shown in the table 1.
Table 1. Cultural Digital Twins.

| Type                          | Number | Representative Cases                                      |
|-------------------------------|--------|----------------------------------------------------------|
| Museum                        | 4      | Haihunhou Ancient Tomb Excavation                        |
|                               |        | The Root of Shanghai: Guangfulin Relics                  |
| Chinese Civilization          | 1      | Distant Source & Long Stream                              |
| Regional Culture              | 4      | Shanghai (Haipai) Culture                                |
|                               |        | Zhejiang Culture Project                                 |
| Intangible Cultural Heritage  | 2      | Chinese ICH Resources                                    |
| City Planning & Development   | 4      | Shanghai - Global Excellent City By 2035                 |
|                               |        | Famous Historic & Cultural City Suzhou                   |
| Characteristic Town           | 13     | XinChang Ancient Town                                   |
| Famous Brand                  | 3      | Shanghai’s Four Brands                                   |
| Famous Person                 | 1      | Chinese Playwright Cao Yu                                |
| Total                         | 32     | Cultural Digital Twins                                   |

Driven by real requirements, it can be seen that all these pilots are closely aligned with current national and regional development objectives.

4 museum prototypes illustrated that the digital twin will be a feasible approach for building virtual museums to ‘make museums and relics come alive’ an objective specified in the national action plan for “Internet + Chinese Civilization”. Constrained by physical space, only partial relics can be exhibited in turn by current museums. Contrastingly the digital twin museum makes all items exhibition possible on a 24x7x365 basis. It can support not only real exhibits but also stories behind with accessible illustrative resources linked.

The regional culture is essentially an abstract macro concept, always giving a vague and elusive feeling. Interestingly enough, after building a digital twin for Shanghai and Zhejiang culture, we surprisingly found the replica in the cyberspace had become full-fledged and ‘visualized’, giving readers more intimate and realistic feeling, knowing what contents these culture have and helping in additional study with rich resources linked. This is probably the benefit from combining virtual and real thing.

In view of visible and structured features existed in the digital twin approach, it is our recommendation to apply them as a cost-effective mean to speed up the dissemination of Chinese excellent traditional culture. This is also an in-time appeal on that it is a right time to systematically summarize the broad and profound Chinese traditional culture and integrate all related resources to maximize its inheritance value.

The knowledge-Graph based digital twin will be an ideal approach for this purpose, which can support a crowdsourcing methodology based on a simple idea, that is, a big digital twin is composed of many smaller twins via IoCs and IoK or a large service is combines with a chain of smaller services via IoSs. By mobilizing all-side positive factors, it turns out a virtual distributed resources base with dynamic evolution. These valuable cultural resources, as a core component in the national public cultural service system, can be readily shared by all people via the so-called cultural cloud services to provide on-demand culture acquisition.

In Shanghai, a cultural cloud service has been provided for years. However, the initial version put its focus merely on solving the match problem of supply and demand, thus more like a cultural e-business system. For cultural cloud, we prefer to hold a perspective on “Content is King” to draw value from cultural contents. For illustrating, we rebuild the Jiading cultural cloud, the origin of Shanghai cultural cloud, with a digital twin model to stress on Jiading’s “city of cultivation” feature. We are looking forward to seeing a Shanghai Haipai cultural cloud soon.

To promote a flourishing culture in the Internet era, it is critical to ensure a practical development methodology enabling professional cultural workers to be a main body of creative work as they know well the value of cultural contents and how to make a rational choose. The digital twin approach has a major advantage for that. The only thing have to do for a cultural worker, without knowing any IT knowledge and skill, is to write a ‘cultural story’ for a targeted topic as he was familiar before. The knowledge graph for him just likes an arrangement for chapter and sections, listing the main points to be narrated and selecting proper reference resources. The cultural worker
act here like a writer and director. The IT worker, like a stage art designer, is responsible for seeking best display for each content, using multimedia, VR/AR etc.

During the prototype development, we fully utilize the existing functionality of PPT tool to edit the knowledge graph and implement connections for IoK/IoCs. As a result, all digital twin prototypes can interactively run on the PPT platform which acts as a simulator of digital twins. Conversely it turns into an advantage of this approach. In other words, anybody may develop and execute a digital twin he wants, provided he can write and run a PPT without any additional tool. The final product can be generated by an automatic tool from the PPT file. This will encourage more people engagement in the co-creation of digital twins.

For any major cultural engineering, wide engagement is highly demanded. The digital twin approach is an ideal platform to support the crowd-work. Each participant can quickly locates his contribution point by navigating the knowledge graph. Once seizing up whole situation, based on his expertise and resource advantages, he can speak his unique “small story” to complement a more vivid ‘large story’. While adopting same building approach, the new contents can be integrated into the system by a simple link without any complex interface issue.

Another interesting question: can we build a digital twin for people? Two ideas have been proposed so far, they are: Building a vivid image by using 3D virtualization techniques to awaken a live recollection. By collecting real-time body data to monitor a person’s health status. The third approach suggested by us is ‘to compile a complete story about a person life’, which has a great significance specially for famous people in view of its great educational value. A sample project for the ‘Chinese Shakespeare—Cao Yu’ is in progress now.

Digital Twin Prototypes in Knowledge Domain

How can transform China from a labor-intensive country into a talent-driven power nation? It needs an out-of-the-box thinking to build an extra-wide channel for fostering millions of professional talents for each domain in meeting the needs of industrial development. Only squeezing into a single-plank bridge towards high schools has become a hard bottleneck in China. Moreover, knowledge update of on-the-job workers cannot compete with tight university’s resources by the same reason.

Building digital twin majors on Internet will be a new shortcut to cultivate professional talents. Learning resources are well organized by the domain Body of Knowledge (BoK) which specified the required knowledge and skills of a qualified professional.

The convergence of IoK and cloud computing will promote a upgrade form ‘Data Cloud’ to so-called ‘Knowledge Cloud’[4], which will create a platform for massive learners to gain on-demand knowledge acquisition with self-pace at anytime and anywhere—a more ideal lifelong learning system. Some experts claimed that the knowledge cloud will be “the Future of the Future” and “What we lack is not brains but the ability to connect ideas” [5]. We also call it as a new internet application—‘Knowledge Superhighway’, succeeding to the Information Superhighway, facilitating millions professionals stepping in a highway towards the knowledge peak.

Based on this idea, we have developed 38 digital twin prototypes for domain knowledge, including some hot information technologies such as cloud computing, IoTs, Big Data etc. The following table give some examples related software engineering techniques:
Table 2. Digital Twin Majors for Software Engineering.

| Body of Knowledge          | Sponsor | Books Linked |
|----------------------------|---------|--------------|
| Software Engineering       | IEEE, ACM | 3825        |
| Project Management         | PMI     | 655          |
| Software Quality           | JUSE    | 427          |
| Software Testing           | ISTQB   | 927          |
| Agile Development          | CASDA   | 506          |
| Software Process Improvement | IIISP | 722          |
| Service Science, Mgmt, Eng, Design | IBM  | 405          |
| Service Computing BOK      | IEEE    | 610          |

In recent years, the MOOC (Massive Open Online Courses) model is changing the educational landscape and rising as an educational innovation, promoting globalization, open access, and democratization of knowledge. The digital twin solution proposed in this paper has a general sense in resources linkage, thus covers naturally the MOOC as well. In fact, the digital twin approach adheres to same principles, like Massive, Open, Online i.e. MOO, but with more resource types available, so that we can call it as MOOK (Knowledge) and MOOL (Learning), promoting a paradigm shift from “Teacher-Centered” to “Learner-Centered” [6].

The digital twin knowledge approach can also be applied to provide knowledge services for national strategic development projects. The following table shows some prototypes already developed:

Table 3. Goal-Oriented Active Knowledge Services.

| Project                                  | Books Linked |
|------------------------------------------|--------------|
| Marine Economy                           | 8439         |
| Made in China 2015                       | 6964         |
| Internet Plus Action Plan                | 10217        |
| National Security                        | 1407         |
| Urban and Public Governance              | 7604         |
| Innovation Techniques and Methods        | 1304         |
| New Product Development                  | 1300         |

Conclusion

All prototypes developed so far were dedicated to verify feasibility and availability of the proposed approach, a typical problem-driven process. Endless requirements for new applications stimulated us a continuous exploration in many unfamiliar domains without any cessation until 70 prototypes produced. This is perhaps a feature of the digital transformation era, existing so many opportunities to be explored. The universality of digital twin approach is well proved in all these experiments, I guess, as the digital twin itself is just a natural option of any digital transformation. High level abstraction of underlying knowledge graphs is another reason for their availability. As shown already in this paper, the digital twin for everything will be a suitable idea and solution with distinct trait of the time for many IT applications in the 4.0 era.

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