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Campus as 'Canvas' : Regional Revitalization in general with location-based Augmented Reality and Co-creation

Supervisor Nakajima Tatsuo
Area of Study Computer Science

Waseda University
School of Fundamental Science and Engineering
Department of Computer Science

1W17BG08-2 Hu Yong-Hao

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Abstract

This is my abstract...

Acknowledgements

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Contents

List of Figures

List of Tables

Chapter 0

Notations

Sample notations Table 1

Table 1: Mathematical notations

Symbol	Meaning
α	learning rate
γ	discount factor
S, s	state
A, a	action
R, r	reward
τ	a trajectory / an episode
G	return
t	a discrete time step
G_t	return at time step t
T	final time step of an episode
π	policy
π_θ	parametrized policy with parameter θ
$\pi(s)$	the action distribution given state s under policy π
$\pi(a\|s)$	probability of action a given state s under policy π
$\mathbb{E}$	expectation
$\mathbb{E}_\pi$	expectation under policy π
$v(s)$	state value of state S
$v_\pi(s)$	state value of state S under policy π
$q(s, a)$	action value of action a on state s
$q_p i(s, a)$	action value of action a on state s under policy π
σ	activation function

Chapter 1

Introduction

This study attempts to implement Location-based Augmented Reality and user Co-creation on Regional Revitalization for a campus and aims at generalization to other places.

1.1 Motivations

As the pandemic of COVID-19 spreading throughout the world since 2020, people were forced or encouraged to stay home and restricted from accessing public places, including tourist attractions, shops, workplaces, schools, etc. Humans' freedom in physical space is restricted, which accelerate the progress of digitalization. Not only entertainment but more and more economic and even academic activities are moving online. As the pandemic slowing down recently, despite the resumption of some physical activities, there are places or facilities remaining unused or abandoned due to financial problems, amount of users not recovered, digitalization of activities, and so on.

Removing the unused places or facilities is an alternative, but if it is possible to give them new values or change people's image of them, they can play different roles and keep contributing the society or enrich the environment. In fact, the concept 'Regional Revitalization', which referes to the attempts to vitalize rural towns where population is falling, by making use of local speciality combined with new ideas to develop new and unique industries such as tourism, has been applied around Japan recently. Among cases of Regional Revitalization, some of them adopt location-based Augmented Reality to help enrich the space. Location-based Augmented Reality is defined as Augmented Reality that utilize geographical information to display contents corresponding to a physical location. It has already used in

not merely entertainment, where Pokemon GO is a famous example, but also implemented in tourism and education, which implies its versatility and practicability. With the application of location-based Augmented Reality and the reference of Regional Revitalization, transformation of an unused place or facility without physical reconstruction seems to be feasible.

Current Regional Revitalization requires considering local unique specialties or features, which takes resources and time to create suitable contents, not to mention public facilities like schools, business buildings, transport hubs which are usually lack of unique specialties or features usable for revitalization, especially for tourism cases, one of the most common applications of regional revitalization. Fortunately, these places have one property in common: users. It may be an alternative for these places to invite users back to create contents based on them, complementing the lack of local uniqueness, attracting more users back and realize their revitalization. We suppose that with the help of Augmented Reality, users can enjoy and create contents with less cost. Although encouraging users back to places where they don't go anymore to create contents becomes another problem, we consider user-user interaction a possible solution since there are works showing positive effects of user-user interaction on users engagement.

Finally, the buildings in our campus are mostly white or silver, and students always describe the landscape as a factory; meanwhile students accessing the campus has become much less after the pandemic. These two reasons has become the initial inspiration for us to add more colors on our campus to make it looks more vivid as well as attract more people to come back.

1.2 Objectives and importance

There are several research questions in this study:

> We examine whether Location-based Augmented Reality with user co-creation does
>
> - Make a place more attractive
> - Change a place's image for users
> - Form interaction between users

In this study, firstly we aim at answering the above research questions, and we expect the results are positive. Furthermore, we try to figure out the possibility to revitalize the campus as a response to our initial inspiration, and generalize the concept and experience to not only campus but also other public facilities or places.

As for the importance of this study, firstly we tend to revitalization locations in general, different from current cases of Regional Revitalization that are usually applied on rural region and in tourism or education orientation. Also, we let users comprise the contents, instead of considering specific characteristics of each location and customize the contents on the side of service provider. Last but not least, we attempt to prove a possibility, focusing less on improving Location-based Augmented Reality in technology aspects like the accuracy of geographical information or object displayment.

1.3 Overview of this paper

This paper consists of 6 chapters, beginning with this chapter for introduction. Chapter 2 explains background knowledges and concepts behind this study, including pandemic's impact, Regional Revitalization, Location-based Augmented Reality and Co-creation. Chapter 3 introduces previous studies related to ours, and compares our work with them to make our work's importance more explicit. Chapter 4 explains the methodology in this study, including a concept model, prototype we built, and details of user experiment. Chapter 5 conducts analysis and discussion on presented results from the user experiment. Chapter 6 draws a conclusion, mentions limitation in this study, and proposes possible future works.

Chapter 2

Backgrounds

2.1 Pandemic's impact

Google has been collecting their users' mobility data since the beginning of 2020 [1] [2]. Results indicate that people do access public places, including transit stations, workplaces and parks, less than before pandemic started spreading. The pandemic also accelerate the process of digitalization [3], which also resulted in a decrease of people commute physically. There are also investigations indicating that more than tens of thousands of store closed in Japan during the pandemic. Other investigations show that remote working has becoming a permanent phenomenon around the world [4]. In Japan, government even made a policy to discourage employees to commute physically. The above situations resulted in more unused facilities left on the society. The U.S. government holds about 45,000 underused or underutilized buildings according to an investigation by Harvard Business Review [5].

2.2 Regional Revitalization

Regional Revitalization is proposed by Japanese government, aiming at combining local unique features or specialties and new ideas or technology, in order to stimulate rural economics to balance the gap between cities and rural areas [6].

Common approaches include improving quality or design of existing local products with new techniques, launching new industries with local features, and broadening promotion on SNS or other media. Of course, a standard does not exist in the field of Regional Revitalization, and there are different cases adopting diverse approaches, such as inserting real landscapes or local products into dramas or animations to attract audience, or inviting artists

to create graffiti at shopping streets to get their customers back [7][8][9].

As the development of Augmented Reality, there are also cases implementing Augmented Reality in their revitalization projects, such as placing a virtual castle on a historical ruin [10] and displaying interactive digital contents beside local physical exhibits [11][12].

2.3 Location-based Augmented Reality

Augmented Reality (AR) utilizes camera on smartphone or glasses to capture the landscape of real world, and then displays digital contents on the captured landscape so as to combine digital information with reality. Location-based Augemnted Reality makes use of geographical information such as GPS data or feature points of a landscape, so that displayed contents are located corresponding to a specific location. Pokémon Go is one of the famous cases of Location-based AR, which displays virtual characters 'pokemons' based on geographic coordinates around the world and requires players to move physically to catch them [13]. The game has earned more than 5 billion dollars since its launch 5 years ago [14], indicating the enormous popularity it possesses.

Beside entertainment, Location-based AR is also applied in tourism and education cases, including displaying educational resources on a tablet when getting close to a spot in an archaeological site [15], or asking a user to challenge a quiz on one's smartphone when approaching a historical building [16].

2.4 Co-creation

Co-creation, in business context, is defined as a company involving its customers in the creation of products or services to suit customers' own context [17]. In a general context, it is also defined as any act of creativity that is shared by two or more people [18]. Co-creation can happen not merely between a company and its customers but also in occasions where value creation is conducted by ordinary people together [19]. Co-creation is also studied in fields of design [18], innovation [20], public sector [21], etc.

In our study, we adopt the more general definition, and we refer to researches about co-creation in different context, which will be introduced in the next chapter.

Chapter 3

Related Works

3.1 Location-based AR's effect on a place / how users view the place

Hwang et al. developed a location-based AR learning system for supporting local culture courses. For students who used the system in field trips, an enhancement in their local culture identity, identification of the culture in a place where one lives, is observed [16]. Law created a mobile app which features a navigation map and pop-ups of educational resources when a user approaches a site physically, and the study implicates the potential of location-based AR to enhance and disseminate the value of cultural heritage [15]. These studies investigate the influence of Location-based AR on the place or on how people value the place, while they focus more on educational goals, and their systems were developed for specific cases, which requires more knowledge and cost to implement.

Chan et al. attempted to integrate location-based AR and virtual currency to connect travelers and local shops, form a new tourism ecosystem and further build an offline business network [22]. The system Chan et al. developed is less case-specific, but their investigation is only adapted to the field of tourism business.

Therefore, we began to be curious about the influence of Location-based AR on the place or on how people value with a more general and less case-specific investigation.

3.2 Location-based AR's effect on users' motivation

Laato et al. found that a location-based AR game motivates players to go outside even during pandemic [23]. Lee et al. proposed a framework describing reasons of stickness to location-based AR game, and their analysis indicates positive influences by satisfaction and sense of flow [24]. Both of the studies chose Pokemon GO as their target to analyze how Location-based AR affects users' motivation, while Pokemon Go's gaming features are also included in their proposed model. Despite Pokemon GO's leading awareness among all location-based AR games, Lee et al. pointed out that other location-based AR games also deserve investigation [24], and we consider that an examination on not a game but a more general location-based AR service would be more representative.

Lacka's assessment indicates that full-fledged location-based AR games played in tourism destination support users to acquire knowledge about the place, which subsequently enhances users' visit intention [25]. Research conducted by Chan et al. mentioned above also investigated how their AR implementation motivates travelers to engage in more extensive and deeper travel experiences [22]. Lacka focused more on tourism and learning aspects, and Chan et al. also investigated about tourism, which are the most focused fields in researches about AR recently, and we believe that more investigations of motivation from other aspects would help location-based AR be applied in more situations.

3.3 Co-creation's effect on a place and users' motivation

Destination image, a term in tourism context, is defined as the aggregation of people's subjective perception, including beliefs, ideas and impressions, associated with a destination [26][27]. Yilmaz's paper points out the lack of studies about how destination image occurs over time, despite destination image being studied much in tourism literature, and the paper presents an approach to realize the formation of destination image with co-creation [28]. Vries et al. built a model of antecedents of destination image co-creation and examine the effect of each antecedent [29].

The concept of destination image is similar with our idea about people's image of a location, and both Vries et al. and Yilmaz's researches about destination image with co-creation indicate the potential of co-creation to

influence people's image of a location in our study.

In addition, Vries et al. examined about customer engagement with Facebook brand pages, and they confirmed the influence of co-creation value on customer engagement [30], which we consider as a precedent to prove co-creation's possibility to improve users' motivation.

The studies introduced above focus specifically on tourism or business viewpoint, which provides us a room to develop our study in a broader context.

3.4 User-user interaction's effect on engagement with co-creation

Studies show that desire to contact or socializing between users motivate users to participate in co-creation activities [31][32]. Waseem et al. also found that interpersonal engagement is one of the key drivers that evoke motivations among employees to facilitate value co-creation [33]. The influence of community in triggering users to engage in co-creation is examined as well [34][35]. From these studies we confirmed that interaction between users works well on motivating people to participate in co-creation, so we attempted to include interaction between users into our work as well to examine its effect on the context of co-creation with location-based AR.

3.5 Location-based service or AR with Co-creation

Cases of co-creation implemented in location-based services or AR application also emerged in recent years. Anttoni Lehto et al. presented an adoption of co-creation which allowed students to initially create contents for a location-based AR learning platform [36]. Jorge Bacca et al. proposed a framework to utilize co-creation in designing motivational augmented reality for vocational education and training [37]. Alavesa et al. developed a location-based AR client for their living labs, which is described as an environment involving users into innovation [38]. Leung et al. proposed a smart service network to realize co-creation of interactive dining experiences using location information [39]. Slingerland et al. include users in the design of game activities to examine what kind of location-based activities citizens prefer to interact with neighbours and explore their neighbourhood [40]. With such a number of precedents, we believe that our idea, which includes im-

plementation of location-based AR and co-creation together, is worth to be conducted and examined.

Chapter 4

Methodology

4.1 Proposed Framework

Reviewing a variety of regional revitalization cases, we sketched a diagram at Figure 4.1 to summarize their common mechanism. In a common case of regional revitalization, the authority makes use of local specialties and applies new ideas with technology to improve existing industry or establish a new one, usually a tourism business, which succeeds to attract more people to visit the place and activate local economy.

We also sketched a diagram at Figure 4.2 to describe a common mechanism of regional revitalization that implements location-based AR. In such cases, the authority applies new ideas on local features to compose unique contents for a location-based AR service, which motivates people to access the place more, resulting in an improvement in local economy. Despite that the contents are in digital form or accessible online, the system's location-based characteristics still make it to encourage visitors to access physically.

For places like public facilities where there is a lack of local features usable

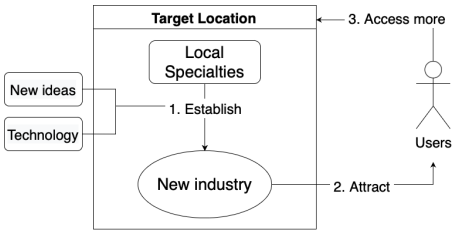

Figure 4.1: Common framework of Regional Revitalization

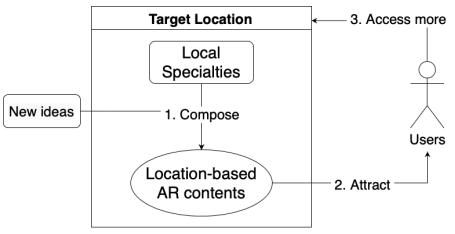

Figure 4.2: Framework of Regional Revitalization with location-based AR

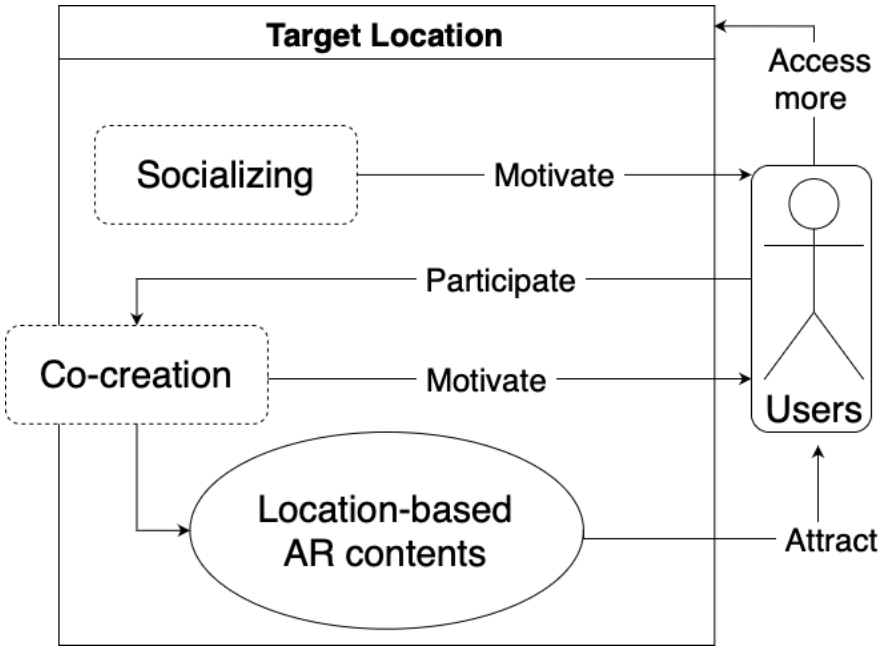

Figure 4.3: Proposed framework: Revitalization with location-based AR and Co-creation

to attract visitors, we presented a framework, sketched in Figure 4.3, that adopts a common characteristic of the places: users. In our assumption, by enabling users to engage in co-creation of contents, which can be conducted digitally with low costs in a location-based AR system, we anticipate that the problem of lacking usable resources becomes solvable. Besides the issue of content creation, From Section 3.1, 3.2 and 3.3 we understand the influence on users' motivation and images about a place by both location-based AR and co-creation, which are both included in our framework. We also introduce a socializing mechanism to encourage users to participate in the co-creation process. From Section 3.4 we understand that interaction between users improves people's engagement with a co-creation activity.

For this framework we proposed, we developed a prototype according to the idea of the framework, and later we examined the proposed framework with an experiment with the prototype.

4.2 Prototype

The prototype is a Web AR mobile app, where users paint their own virtual graffiti, view other users' graffiti, and create graffiti based on other users'

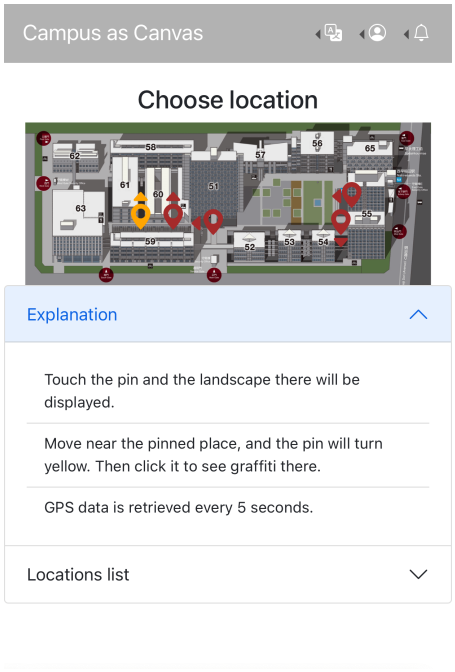

Figure 4.4: Prototype screenshot: Home page

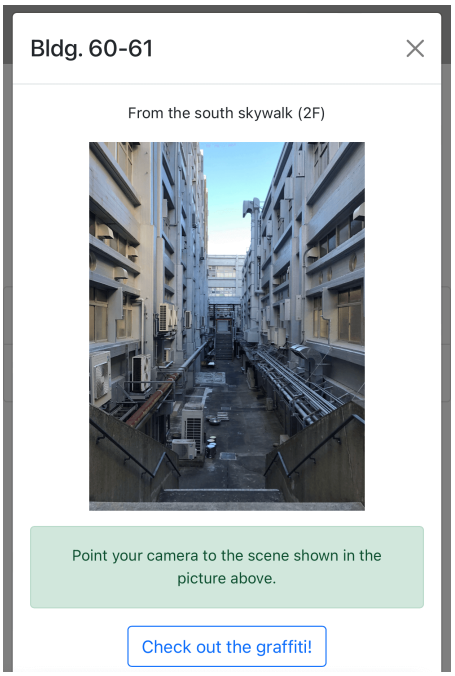

Figure 4.5: Prototype screenshot: Picture for confirming the location

ones around Nishi-Waseda Campus of Waseda University. We deployed the app on web instead of publishing a native app, so that users with a mobile device of any brand can easily access the service on their web browsers. The front-end part is built with ReactJS (Javascript), and the back-end part, handling authentication, database and storage, is served by Google Firebase. The functionality of location-based AR is implemented with AR.js, A-Frame and Javascript Geolocation API.

The prototype was supposed to enable creating graffiti at any place in the campus, but due to the consideration of unsufficient GPS accuracy and security issues, we restricted the places where graffiti are visible to several specific locations at campus. In Figure 4.4, the prototype displays pins on the specific locations. The device's GPS information is retrieved to confirm where the user is. When a user gets close enough to one of the pinned locations, the corresponding pin turns yellow to indicate that the graffiti there is available to access. In Figure 4.5, when a pin is touched, a picture of the location is displayed so that the user can confirm the exact location and face to the correct orientation.

After confirming the location, the app switches to AR mode by turning on the camera, and graffiti are displayed with the real landscape as a back-

Figure 4.6: Prototype screenshot: Graffiti displayed in AR mode

Figure 4.7: Prototype screenshot: A graffiti painted based on other ones

ground, as shown in Figure 4.6. The menu on the bottom displays a graffiti's title, description, 'Like' button, button to check the same user's all creation, and a 'New!' button to open a painting canvas. There are also buttons on the left and right to switch between different graffiti. For graffiti painted based on other ones, as shown in Figure 4.7, there is a 'Based works' button to display the previous graffiti which this one is based on.

With the features of A-Frame, each graffiti is located on its specific angle, recorded during creation, to fit the background landscape, as demonstrated in Figure 4.8.

On clicking the 'New!' button, as shown in Figure 4.9, the user can choose between creating a new graffiti and painting on another user's graffiti, and then a canvas is expanded with basic painting tools equipped, as shown in Figure 4.9. Last but not least, whenever a graffiti is 'liked' or someone painted another graffiti based on this one, the author receives notifications in the app.

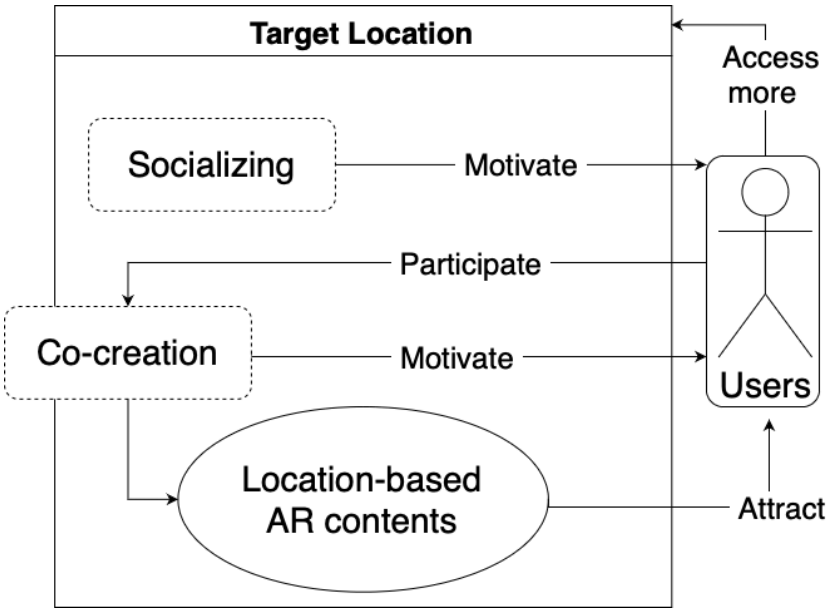

Figure 4.8: Prototype screenshot: Graffiti displayment in different angles to fit itself to the landscape

In the prototype, content co-creation is realized by graffiti painting only by users, and user-user interaction is implemented by functionalities of 'like' and painting basd on other users' graffiti.

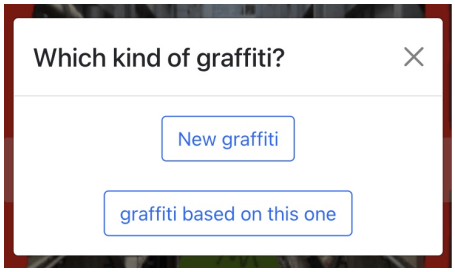

Figure 4.9: Prototype screenshot: Menu for choosing the type of graffiti painting

Figure 4.10: Prototype screenshot: Canvas and tools for graffiti painting

Chapter 5

Experiment and Results

5.1 Evaluation

5.1.1 Evaluation Targets

In the proposed framework, there are several components we have to evaluate in order to answer our research questions. The following list explains the targets to evaluate, and Figure 5.1 indicates where the targets are located in our proposed framework.

- T1: Motivation to access the campus by location-based AR contents
- T2: Motivation to access the campus by co-creation process
- T3: Motivation to access the campus by interaction between users
- T4: Changes in the image of the campus by location-based AR contents
- T5: Changes in the image of the campus by co-creation process
- T6: Changes in the image of the campus by interaction between users

5.1.2 Evaluation of Motivation

To evaluate targets about motivation, including T1, T2 and T3, we adopted questions from Situational Motivation Scale (SIMS) [41] for measurement.

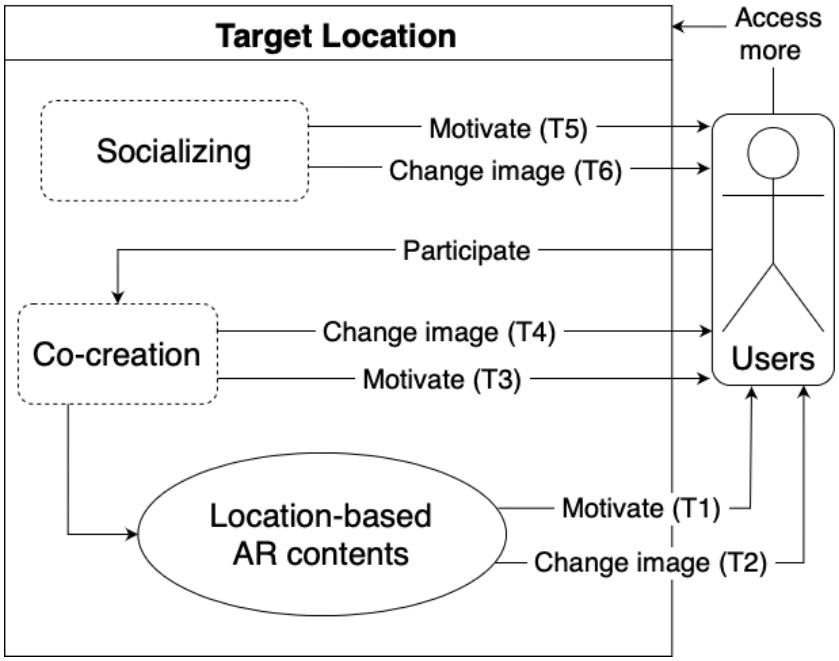

Figure 5.1: Proposed framework and targets to evaluate

SIMS contains four categories of motivation: 'Intrinsic motivation', 'Extrinsic motivation', and 'Amotivation', while in this study we specifically adopted 'Intrinsic motivation (IM)' and 'Amotivation (AM)'. 'Extrinsic motivation', including 'Identified regulation (IR)' and 'External regulation (ER)' are excluded since what we wanted to measure is the motivation induced by components in the proposed framwork, instead of following any instruction, obiligation, or any other external factors. Questions we adopted from SIMS are listed in Appendix A. Here we adopted 6 point scales to avoid ambiguous responses (where users keep choosing the middle item).

Cahyono et al. adopted SIMS with the use of Self-Determination Index (SDI) for scoring, which is calculated by the formula below:

$$SDI = (2 * IM) + IR - ER - (2 * AM)$$

The higher the value of SDI, the more intrinsically motivated a person is [42]. However, since we excluded IR and ER in this study, we conducted the scoring with:

$$IM - AM$$

and composed hypotheses for the scoring of motivation, listed below:

- H1: For T1, the value of IM - AM measured with SIMS is positive.
- H2: For T2, the value of IM - AM measured with SIMS is positive.
- H3: For T3, the value of IM - AM measured with SIMS is positive.

Besides the scales, we also prepared questions for free comments about motivation.

5.1.3 Evaluation of Changes in the Image of the Campus

To evaluate targets about changes in the image of the campus, including T4, T5 and T6, we prepared a question with 5 point scale, described as follows:

Does the image of campus in your mind changed?

1. Not at all
2. Only a little
3. Somehow changed
4. Changed a lot
5. Completely changed

Besides the scales, we also prepared questions for free comments about changes in the image of the campus.

5.1.4 Questionnaires

Then we designed 4 questionnaires prepared for participants in an experiment conducted later (explanation in section 5.2). Each questionnaire corresponds to a topic listed as follows:

1. Viewing location-based AR contents, the graffiti, in the campus
2. Creating location-based AR contents, the graffiti, in the campus
3. Interactions with other users
4. Overall experience of using the prototype

In each questionnaire, we asked questions about how the experience of the topic during the experiment affected one's motivation to access the campus, with questions introduced in Section 5.1.2, as well as changes in the image of the campus in one's mind, with questions introduced in Section 5.1.3. For example, Questionnaire 1 includes questions about the motivation and changes in the image of the campus influenced by the experience of viewing location-based AR contents in the campus.

Results from Questionnaire 1 correspond to the evaluation of T1 and T4, Questionnaire 2 to T2 and T5, Questionnaire 3 to T3 and T6, and finally Questionnaire 4 to the whole framwork. In Questionnaire 3, we also included questions about awareness of other users' existence and interaction with them. Eventually, in each questionnaire, we also asked whether a participant, after attending the experiment, prefers our location-based AR prototype or a similar one without location-based features and AR effect but usable at home, in order to make clear of the importance of location-based AR.

5.2 Experiment

At first, we conducted a preliminary survey with 3 participants trying the prototype in Waseda University Nishi-Waseda Campus for one week. 3 participants gave us positive responses about their motivation to access campus after experiencing the prototype. We also improved the app based on their feedbacks, such as adding features that allow users to review/edit/delete their own graffiti. The experinemt lasted for 2 weeks. 14 males and 2 females participated, and they are asked to use the prototype freely in the same campus at least twice a week. Before the experiment, we asked participants about their frequencies of accessing the campus and the images of campus in their mind before and after the pandemic started spreading, in order to understand how much impact the pandemic brought on each participant. Instruction of using the prototype was also distributed before the experiment. 2 weeks later, after the experiment finished, participants were required to answer the questionnaires introduced in Section 5.1.

We also conducted a control experiment, with 3 males and 1 females participating in playing a similar prototype without location-based features and AR effect but usable at home for a week. Then we asked them to fill in the same questionnaires.

5.3 Results

5.3.1 Motivations

	Intrinsic motivation (IM)	Amotivation (AM)	IM - AM
Mean	4.3906	2.7500	1.6406
Median	4.3750	3.0000	1.6250
Min	3.0000	1.0000	-1.5000
Max	6.0000	4.5000	5.0000
SD	0.7636	1.0124	1.5916

Table 5.1: Motivation to access campus influenced by viewing location-based AR contents

	Intrinsic motivation (IM)	Amotivation (AM)	IM - AM
Mean	4.4833	2.5167	1.9667
Median	4.2500	2.5000	2.0000
Min	3.0000	1.0000	-1.5000
Max	6.0000	4.5000	5.0000
SD	0.8044	1.0021	1.6767

Table 5.2: Motivation to access campus influenced by participation in co-creation

	Intrinsic motivation (IM)	Amotivation (AM)	IM - AM
Mean	4.3833	2.5833	1.7200
Median	4.7500	2.0000	1.8000
Min	2.0000	1.0000	-2.0000
Max	6.0000	5.0000	5.0000
SD	1.1135	1.1286	2.0743

Table 5.3: Motivation to access campus influenced by interaction with other users

5.3.2 Image of Campus

5.3.3 User-user Interaction

5.3.4 Comparison with cases without location-based AR features

	Intrinsic motivation (IM)	Amotivation (AM)	IM - AM
Mean	4.5469	2.5313	2.0156
Median	4.6250	2.2500	2.6250
Min	3.0000	1.0000	-2.0000
Max	6.0000	5.0000	5.0000
SD	0.8328	1.0950	1.8108

Table 5.4: Motivation to access campus influenced by overall experience of the prototype

	Viewing location-based AR contents	Participation in co-creation	User-user interaction	Overall experience
Mean	2.6875	2.7333	2.8667	2.8750
Median	3.0000	3.0000	3.0000	3.0000
Min	2.0000	2.0000	2.0000	2.0000
Max	4.0000	4.0000	4.0000	4.0000
SD	0.6021	0.5936	0.8338	0.8062

Table 5.5: Changes in the image of the campus, scaled from 1 (Not at all) to 5 (Completely changed)

	I felt existence of other users	It felt like I am interacting with other users
Mean	4.5333	4.0000
Median	5.0000	4.0000
Min	3.0000	2.0000
Max	6.0000	6.0000
SD	0.9155	1.3093

Table 5.6: Sense of other users' existence and interaction, scaled from 1 (Disagree) to 6 (Agree)

	Viewing location-based AR contents	Participation in co-creation	User-user interaction	Overall experience
Mean	4.8125	4.8667	4.6000	4.7500
Median	5.0000	6.0000	5.0000	6.0000
Min	1.0000	1.0000	1.0000	1.0000
Max	7.0000	7.0000	7.0000	7.0000
SD	1.6419	1.8074	1.6388	1.8074

Table 5.7: Preference between prototype at campus or prototype at home, scaled from 1 (At home) from 7 (At campus)

Chapter 6

Results and Discussion

6.1 Motivations

6.2 Image of Campus

6.3 User-user Interaction

Chapter 7

Conclusion

7.1 Conclusion

7.2 Limitations

7.3 Future Works

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APPENDIX A - Machine Specs

Table 7.1: Machine specs

Item	Value
CPU	Intel Xeon E5-2690
Memory	188G
OS	18.04.5 LTS (GNU/Linux 4.15.0-121-generic x86_64)

APPENDIX B - Derivation of the simplest form of policy gradient

Derivation of the simplest form of policy gradient is provided below.

$$\begin{aligned}
\nabla_\theta J(\pi_\theta) &= \nabla_\theta \, \mathbb{E}_{\tau\sim\pi}[R(\tau)] \\
&= \nabla_\theta \int_\tau P(\tau|\theta)R(\tau) \\
&= \int_\tau \nabla_\theta P(\tau|\theta)R(\tau) \\
&= \int_\tau P(\tau|\theta)\nabla_\theta log P(\tau|\theta)R(\tau) \\
&= \mathbb{E}_{\tau\sim\pi}[\nabla_\theta log P(\tau|\theta)R(\tau)] \\
&= \mathbb{E}_{\tau\sim\pi}[\nabla_\theta log \pi_\theta(a_t|s_t)R(\tau)]
\end{aligned}$$

This is a expectation, which can be estimated with a sample mean. Denote the estimated policy gradient as $\hat{g}$:

$$\hat{g} = \frac{1}{D}\sum_{\tau\in D}\sum_{t=0}^{T}\nabla_\theta log \pi_\theta(a_t|s_t)R(\tau)$$