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Athens Journal of Technology & Engineering

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The current issue is the second of the eleventh volume of the *Athens Journal of Technology & Engineering (AJTE),* published by the Engineering & Architecture Division of ATINER.

Gregory T. Papanikos, President, ATINER.

Athens Institute for Education and Research

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- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **27 May 2024**

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Important Dates

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- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **27 May 2024**

Academic Member Responsible for the Conference

- **Dr. Theodore Trafalis**, Director, Engineering & Architecture Division, ATINER, Professor of Industrial & Systems Engineering and Director, Optimization & Intelligent Systems Laboratory, The University of Oklahoma, USA.

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Quality Infrastructure and Sustainable Development: An Empirical Economic Analysis[1]

By Gregory T. Papanikos[*]

Sustainable development is one of the most important goals set by many countries worldwide. The United Nations (UN) has prioritized it as a significant objective within the Sustainable Development Goals (SDGs) program. Sustainable development implies economic growth that benefits both present and future generations without compromising their well-being. Some analysts argue that sustainable infrastructure may be more advantageous when evaluated based on private cost-benefit criteria, although comparisons are needed for clarity. One challenge in testing this hypothesis is the lack of a clear measurable distinction between sustainable and non-sustainable infrastructure at the national or global level. In this study, we utilize two quality infrastructure indices to quantify the extent of sustainable infrastructure. These measures are then applied to a sample of countries to test hypotheses regarding the effect of per capita Gross Domestic Product (GDP) and population on a country's investment in quality infrastructure. The findings support the hypotheses that per capita GDP and population have a nonlinear effect on quality infrastructure, with both variables having a positive effect, albeit at a decreasing rate. At certain higher levels of per capita GDP or population, the effect turns negative. The policy implications for national governments and international organizations are also discussed, highlighting the need for tailored strategies to promote sustainable infrastructure development without undermining other much needed priorities such as eradicating extreme poverty.

Keywords: *development, sustainability, per capita GDP, population, quality infrastructure, marginal effects, elasticity, investment gaps*

Introduction

Since the times of written history, humanity has struggled to fight poverty. Unfortunately, the means were and are scarce, and people had to work hard to make ends meet. Otherwise, as Hesiod put it in the 8th century, "one day's work would have been sufficient to produce all you need for a year" (see Papanikos 2022a). Humanity has made great advances since Hesiodic times, primarily because of investing in infrastructure and continuously improving it, made possible by huge investments in human capital. This has produced new technologies, as beautifully allegorically illustrated by Hesiod's story of Prometheus, who "stole" the well-kept secret of fire. The discovery and learning of how to use fire was a

[*]President, Athens Institute for Education and Research, Greece. The author has taught for many years in Canadian, Greek and U.K. Universities.

[1]An early version of this paper was presented as an invited lecture to a study abroad program on "sustainable infrastructure" organized by Professor Dimitrios Goulias, University of Maryland, USA.

significant step forward in achieving economic development. Using a theoretical model, I examined the macroeconomic implications of technical progress in Papanikos (1994).

Since then, humanity has made great achievements in creating the infrastructure which has permitted greater production of goods and services, and therefore satisfied the needs of more and more people. As explained in Papanikos (2024a), absolute (extreme) poverty has been drastically decreased. This was achieved by building huge infrastructures such as more and better roads, water reservoirs, ports, airports, energy grids, schools, hospitals, etc. To a great extent, this was the result of the industrial revolution, globalization, and more recently, hyperglobalization (Papanikos 2024a). The word “more” identifies quantity, and the word “better” identifies quality. A good example of "more and better" is the metro system of the historical city of Athens. There are three lines: one was constructed in the late 19th century, and the other two lines in the early 21st century. Both serve the same purpose, but a simple use of the three lines will demonstrate what "better" means. The new two lines are not only more numerous, but they are also better. They are safer, cleaner, and more comfortable, both the wagons and the stations. In other words, they are of better quality. There are many other such examples in Greece and elsewhere, relating to all types of infrastructures: old and new roads, airports, ports, schools, hospitals, etc. Some people might wrongly argue that this is simply a matter of maintenance, but it is not. What made them better is not just better maintenance, but also better technology which can be applied to old structures. As many contractors know, it is more expensive to renovate than to demolish and build from scratch.

The question that often arises is how much better we want our infrastructure to be. Economics might have an answer by using the well-known model of demand and supply. Demand implies a desire for both quantity and quality, but both come at a cost. This study discusses several issues related to infrastructure from an economic point of view. The first issue is how much infrastructure and quality infrastructure the world needs. Related to this issue is the estimation of future needs in infrastructure and quality infrastructure, and how the gap between the current trend and the future needs can be reduced.

The second issue relates to scarce resources that should be sacrificed to construct more and better infrastructure. This depends on the availability of resources. At the national and global levels, this is measured by per capita Gross Domestic Product (GDP). The higher the per capita GDP, the higher the demand for better infrastructure. The quality of infrastructure is measured by two indices: The Quality Infrastructure for Sustainable Development (QI4SD) Index developed by the United Nations Industrial Development Organization (UNIDO), and The Global Quality Infrastructure Index (GQII) developed by Germany.

There is both private and public infrastructure. Usually, public infrastructure is considered a public good. Governments pay for it through people’s taxes, but citizens use it for free or for a relatively low fee. The more people use the infrastructure, the higher the welfare benefits from building it. Thus, the higher the population of a country, the higher the demand for more and better infrastructure. For example, if 100 people benefit from a bridge and a plain bridge costs X

amount of euros, then the per capita cost (price) to build the bridge is X/100. If instead, 1000 people benefit, then the per capita cost is X/1000. The lower cost implies that there might be opportunities to build a better bridge which might cost two times X, but still, the per person cost will be cheaper at X/500. Thus, we make the assumption that the size of the population is an important determinant of more and better infrastructure.

To test the effects of per capita GDP and population size, an empirical regression model is developed and tested using the most recent cross-sectional data of per capita GDP, population, and other variables found to be statistically significant. The empirical results enable the calculation of the marginal effects and the elasticities of per capita GDP and population in achieving optimal levels of quality infrastructure.

The remainder of the paper is structured as follows: The second section discusses and develops a simple ad hoc economic model of quality infrastructure, which leads to a statistical specification. The results of estimation are presented in the fifth section of the paper. The needs for infrastructure in general and quality infrastructure, in particular, are discussed in the third section of the paper. The fourth section presents the two indices of quality infrastructure used in the empirical estimation section of the paper. In the same section, summary statistics of these two indices are also presented. The final section is devoted to the discussion of the main results and policy implications of the findings.

A Simple Economic Model of Quality Infrastructure

Long-term economic prosperity has been one of the most important goals set by national governments and international organizations. Higher economic prosperity can only be achieved through higher economic growth, defined as the increase in the total final quantities of goods and services produced in an economy over the years. Economic growth is necessary for improving people's welfare and eradicating absolute (extreme) poverty. A sufficient condition for this is the presence of social policies that distribute benefits to all, but primarily to the less privileged in society. Social and welfare policies provide basic services to the entire community, such as security, healthcare, elderly care, and education.

How can long-term growth be achieved? While there are many controversies in economics, there is unanimous agreement on the role of infrastructure in promoting long-term economic growth, especially in countries with low levels of development, as measured by their per capita GDP[2]. The logic behind this thesis is straightforward: more machines cannot produce less output than fewer machines, more roads cannot produce less output than fewer roads, more bridges cannot produce less output than fewer bridges, and so on. If empirical studies find

[2]Many international, regional, and national organizations, as well as governments, have realized the importance of infrastructure development for overall development. For example, UNCTAD (2011, p. 44) pointed out that "Infrastructure investment and social transfers, for example, are fundamental elements of a long-term development strategy." In Papanikos (1988), I examined the association between investment in construction and post-war Greek economic growth.

negative effects, then one should be suspicious of the quality of data used. This holds true for private investment in building infrastructure, but public investments might have different effects depending on the government's effectiveness and efficiency. This is also influenced by the established political system, such as authoritarian regimes versus democracies[3]. This is important because most mega infrastructure projects are built by public authorities, and historically, without exception, no country in the world has undertaken a public works project without it being associated with corruption, lack of transparency, money embezzlement, and lower-than-expected quality infrastructure. This is a widespread phenomenon, but it should not serve as a justification to refrain from building necessary infrastructure[4]. The word "necessary" should be emphasized. Building more than the necessary infrastructure may have the opposite effects on economic growth. This is to be expected when a country becomes so rich that most of its infrastructure might turn out to be akin to pharaonic works or what economists call conspicuous consumption.

Economics makes a fundamental distinction between intermediate and final goods. Only the final goods are included in the measurement of GDP. Intermediate goods are used to produce other intermediate goods and/or final commodities. However, there are some goods that, depending on how they are used, can be classified as either intermediate or final goods. Take, for example, a road. It is an intermediate good when used to transport raw materials to a factory that produces cars, and it is a final (consumption) good when used by a family of four to visit the nearby beach on a Sunday for leisure. A safe and pleasurable road defines quality infrastructure. "Pleasurable" is a multidimensional concept and includes sustainability[5]. This is actually the criterion for building new infrastructure. It should be safer, pleasurable (increasing people's welfare or utility), and of course, sustainable, as it should not undermine the welfare of future generations.

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[3]What democracy entails is another issue altogether. Unfortunately, we are far from an ideal democracy. Even in ancient Athens, the cradle of democracy, the reality fell short of what great minds like Plato envisioned for a perfect society. This has serious repercussions in the political decision-making process. I have examined the issue of democracy in a series of papers; refer to Papanikos (2022c and 2022d) and the comments made by Meydani (2022) and Petratos (2022).

[4]This is a phenomenon that no country can eliminate. On the issue of corruption and taxes, refer to Papanikos (2015a, 2024b). Sometimes, in countries where there are many hurdles in decision-making, corruption may contribute to economic growth even if it is suboptimal.

[5]Road safety is an important aspect of what is meant by quality infrastructure. This is a matter of great concern for many countries. Numerous studies have examined various aspects of roads and transportation infrastructure; for example, see Ambunda and Johannes (2020), Athanasopoulos (2014), Babu et al. (2016), Degbe and Song (2019), ElSahly and Abdelfatah (2020), Ghuzlan et al. (2015), Heckmann et al. (2019), Kolpakov and Sipiora (2020), Kos et al. (2017), Onyango et al. (2015), Özen et al. (2021), Perić and Scholl (2017), Sisiopikou (2018), and Yankevich (2024). Energy has been also an important issue in the discussion of sustainability and international politics; see Baier and Meier (2020), Balku et al. (2016), Călătan and Dico (2022), Estrada and Lee (2023), Gavotsis and Moncaster (2015), Osorio et al. (2017), Papanikos (2015b and 2015c), Suru et al. (2017), Yasa (2022). Sustainability has influenced the teaching curriculum of engineering courses; for instance, see Issa (2017). It has also affected how cities are planned and developed; for example, see Chen et al. (2016), Hatem (2024), MacLeod et al. (2023), Mazzi and Gatto (2020), Miletić et al. (2023), Negas and Seco (2022) and Nikologianni et al. (2022).

Economics helps policymakers choose among many alternatives in satisfying specific needs for sustainable infrastructure. Various projects are ranked according to their total (private and social) rate of returns. From an economic perspective, infrastructure connects the present, during which time period a decision should be made, with the future, during which periods the benefits from infrastructure are realized. Infrastructures are built by sacrificing current consumption for presumably higher and better future consumption

Thus, one of the determinants of quality infrastructure is the economic wealth of a country. The richer the country, the more sustainable infrastructure can be produced. Infrastructure should also be used by people. The higher the number of people who are served, the higher the demand for such infrastructure, and therefore the lower the cost per person. The combination of these two variables determines not only the quantity of infrastructure (e.g., the number of bridges) but also their quality (sustainability). The richer the country and the more people the infrastructure serves, the higher the quality of infrastructure that can be built. Of course, other variables may play a role. One set of such variables might be captured by dummy geographical variables, such as the continent of the country. This might be a good proxy for different cultures across countries. Thus, a simple economic model of the quality of infrastructure can be depicted as follows:

$$QI = F(Y, N, D)$$

where QI represents the quality of infrastructure measured by an index as explained in the fourth section of the paper; Y represents the richness of the country measured by per capita GDP; N represents population, and D represents dummy variables.

This general function should take a reasonable functional form. It is assumed that the best explicit mathematical form that can explain the quality of infrastructure is quadratic because it allows testing the hypothesis of a negative effect of per capita GDP and population on quality infrastructure. The following is such a function:

$$QI = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 N + \beta_4 N^2 + \beta_5 D_1 + B_6 D_2 + \ldots + \beta_n D_n + U$$

The β's are parameters to be estimated, as demonstrated in the empirical section of the paper (see section five below). D's are dummy variables, and U is the error term.

This function is sufficiently flexible to permit the testing of the following hypotheses:

1. Per capita GDP (Y) may have a positive, negative, or zero effect on quality infrastructure. The sign of the effect may change depending on the level of per capita GDP.
2. Population (N) may have a positive, negative, or zero effect on quality infrastructure. The sign of the effect may change depending on the number of people living in the country.
3. A series of dummy variables that might have a statistically significant effect on quality infrastructure.

The above hypotheses depend on the sign and statistical significance of the parameters (the β's). The t-statistic is used to diagnose whether a coefficient estimate is statistically significant. The F-statistic is used to determine whether all regressors as a group are statistically significantly different from zero. The coefficient of determination is employed to account for the percentage of quality infrastructure variation that can be explained by the variations of the right-hand variables.

It was mentioned above that the quadratic functional form permits the test of a positive or negative effect of per capita GDP (Y). Taking the first derivative of the above equation with respect to Y, the following condition should hold for a positive marginal effect:

$$\beta_1 + 2\beta_2 Y > 0$$

If it is less than zero, then the effect is negative. If both β_1 and β_2 are positive, then the effect is always positive. However, if the β's are of opposite signs, then there might be a value of per capita GDP where this effect becomes negative.

Similar analysis applies to the variable population (N). The necessary condition for a positive effect is:

$$\beta_3 + 2\beta_4 N > 0$$

The estimation of the parameters also allows for the calculation of elasticities (e), defined as the percentage increase of quality infrastructure for a given percentage change in per capita GDP (Y) or population (N). These elasticities are given by the following two equations:

Income elasticity of quality infrastructure: $e_Y = (\beta_1 + 2\beta_2 Y)\frac{Y}{QI}$

and

Population elasticity of quality infrastructure: $e_N = (\beta_3 + 2\beta_4 N)\frac{N}{QI}$

The estimation of the coefficients, the calculation of the marginal effects, and the income and population elasticities are presented in the empirical section of the paper; see section five below.

The next section examines the forecasts of trend investments in infrastructure, the trend of investment needs, and the trend of investment that satisfies the Sustainable Development Goals (SDGs) set by the United Nations.

How much Infrastructure is needed?

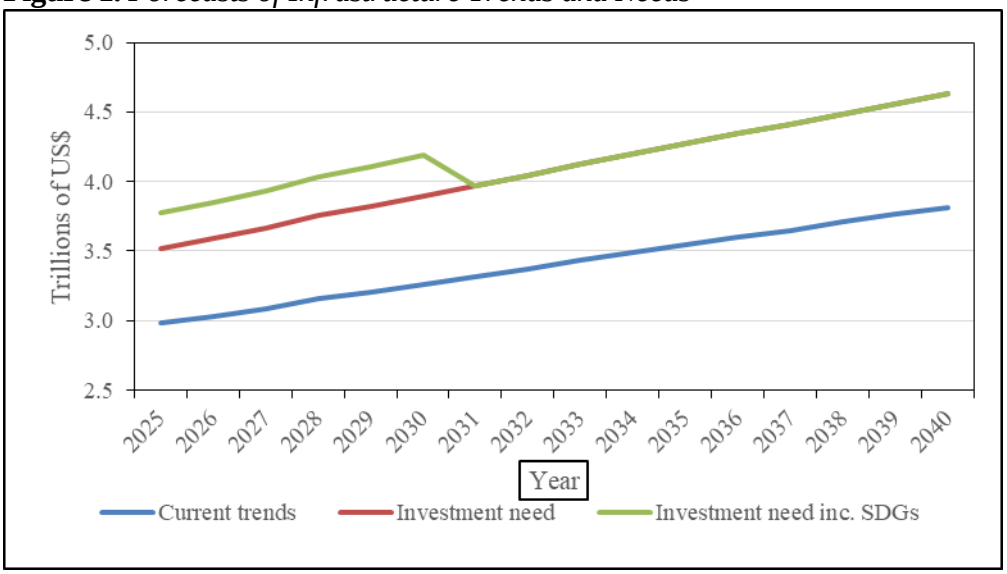
Quality infrastructure requires investment in infrastructure. The question raised by many academics, policymakers, and various organizations is how much infrastructure is needed, or as economists would state it, what is the optimal size of

public infrastructure. Private investment in infrastructure uses market criteria, with the most important criterion being profit maximization.

However, this is not the case for public infrastructure. National governments and international organizations make forecasts on how much infrastructure the world needs. Univariate methods of forecasting are used, which basically assume that past trajectories determine future trends. Figure 1 shows three such forecasts: (a) the trend if the current trajectory of investment continues, (b) the infrastructure that is needed, and (c) the sustainable infrastructure, which is defined as the one that meets the United Nations SDGs. The methodology of forecasting is available in the source shown at the foot of the figure.

The blue line in Figure 1 shows the infrastructure that will be created if the current trend continues. The forecasts are up to 2040. The red line shows how much infrastructure is needed up to 2040, and the green line displays how much quality infrastructure is needed, defined here as meeting the requirements of the SDGs. It is assumed here that the infrastructure and the quality infrastructure needs are the same after 2030. In 2025, the forecast of actual investment in infrastructure is estimated to be $2.98 trillion USD. By 2040, this will increase to $3.81 trillion USD. In 2025, the need for investment in infrastructure will be $3.52 trillion USD, and the need for quality infrastructure will be $3.77 trillion USD. By 2040, both needs will be the same and equal to $4.63 trillion USD.

Figure 1. *Forecasts of Infrastructure Trends and Needs*



Source: Global Infrastructure Hub (https://outlook.gihub.org/).

By 2040, there will be an investment gap of $0.8 trillion USD. However, one might question the linearity of the trendlines. A linear trend of investment implies that investment growth decreases over time. There is no economic justification to assume a declining growth rate. The growth rate of investment depends on the growth rate of GDP, among many other factors. While this goes beyond the scope of this paper, it should be noted that such long-term forecasts can only be used as desired goals rather than as certainties.

The next three figures (Figures 2-4) show the investment gaps in seven different types of infrastructure investment: roads, airports, ports, rail, energy, telecommunications, and water. One way to observe the differences is by examining the change in the investment gap year by year. This is represented by the coefficient of the linear function appearing in each graph. For example, the investment gap in roads is $9.61 billion USD. From 2016 to 2040, this gap accumulates from almost $200 billion USD at the beginning of the forecasting period (2016) to over $400 billion USD at the end of the forecast period in 2040.

Figure 2. *Infrastructure Gap (Needs minus Trends) in Roads*

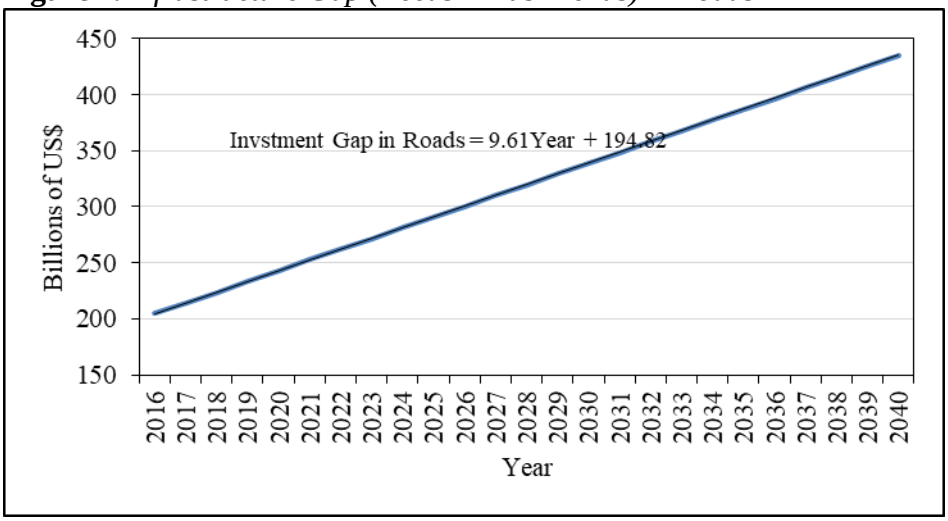


Figure 3. *Infrastructure Gap (Needs minus Trends) in Airports, Ports and Rail*

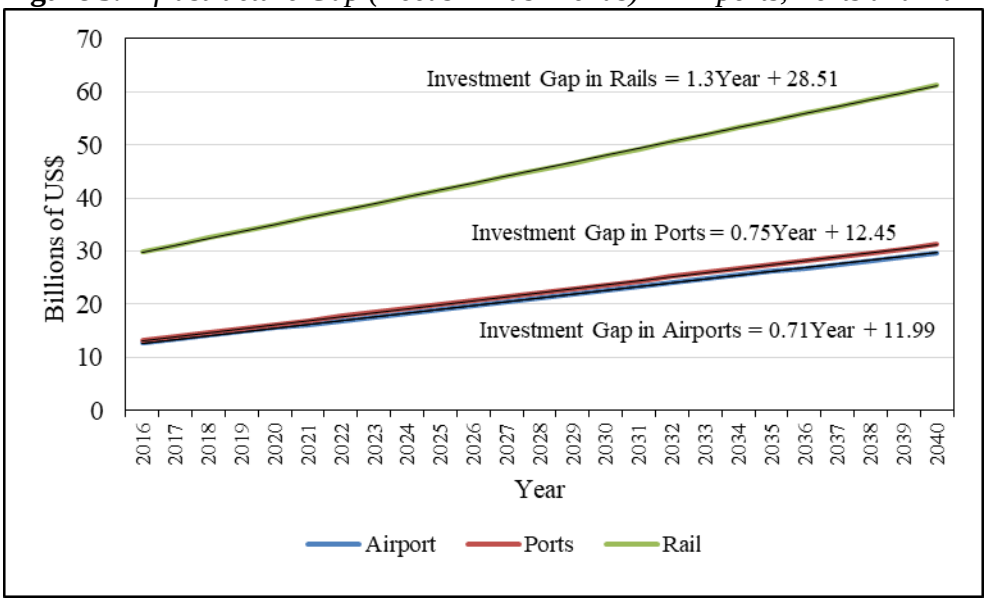
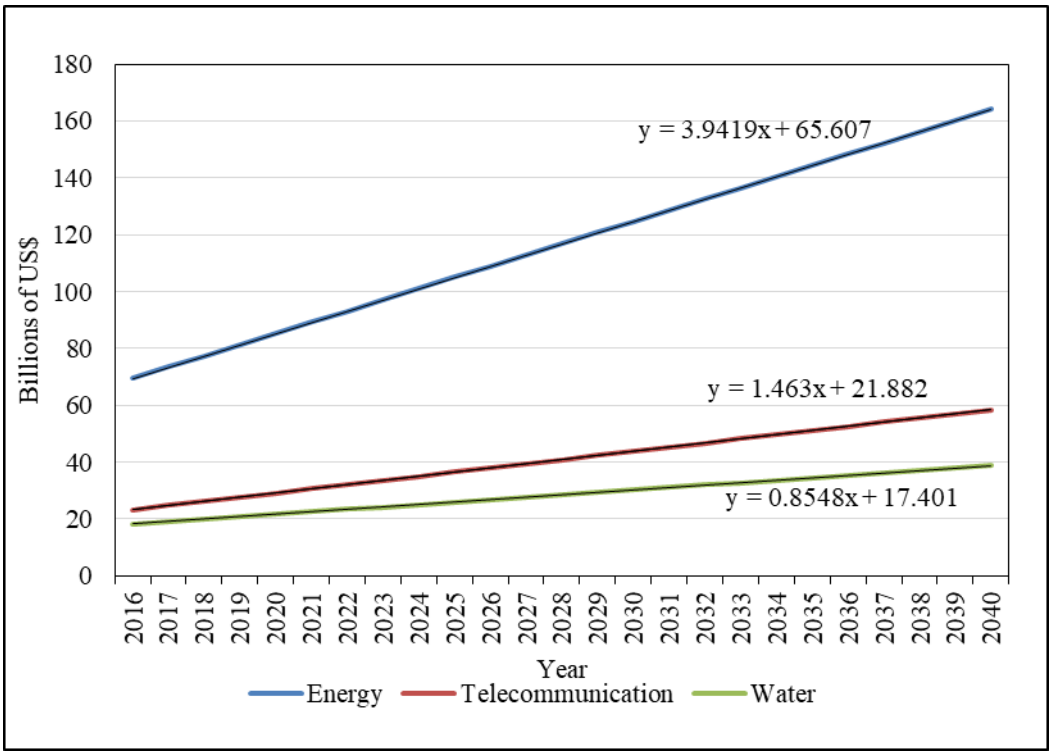


Figure 4. *Infrastructure Gap (Needs minus Trends) in Energy, Telecommunications and Water*



Similar analysis can be applied to the other six investment gaps shown in Figure 3 and Figure 4. In order of importance, the investment gap grows by $3.9 billion USD in energy, $1.5 billion USD in telecommunications, $1.3 billion USD in rail, $0.85 billion USD in water, $0.75 billion USD in ports, and $0.71 billion USD in airports.

These are significant investment gaps, and one may wonder who will finance all these investment projects and how they should be allocated around the globe. One view supports the idea of allocating more to countries that lag behind in economic development, as measured by per capita GDP. If this is true, then per capita GDP should have a positive impact on quality infrastructure when it is low and even negative when it is very high. This hypothesis is tested in the fifth section of the paper. The next section presents the two indices that measure quality infrastructure.

Definitions and Data Sources of Quality Infrastructure

For the purposes of this study, Quality Infrastructure (QI) is considered identical to sustainable infrastructure, which takes into consideration not only private interests but also social concerns regarding the long-term effects that such investment projects might have on the environment, climate change, health, safety, etc. I have examined in detail the economic implications of distinguishing between sustainable and non-sustainable infrastructure in Papanikos (2022b). I argued that

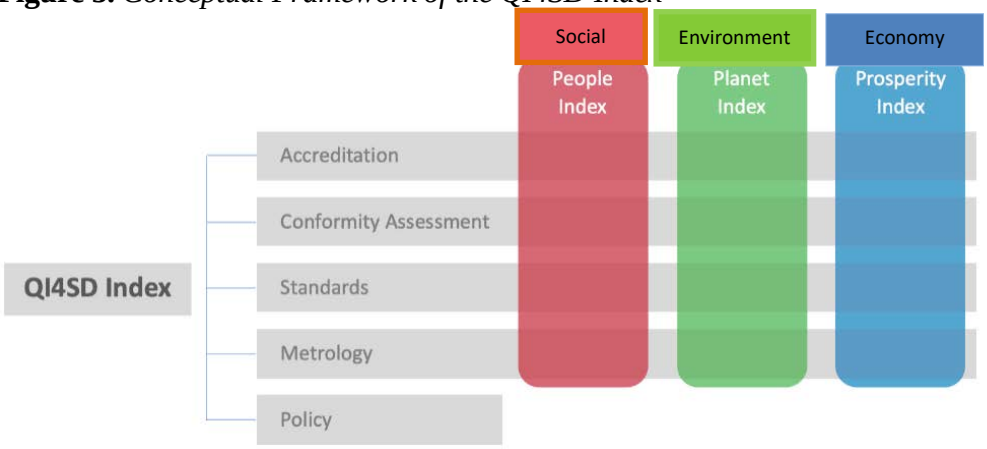
the entire discussion about the sustainability of investment projects stems from the higher opportunity cost this type of investment incurs relative to non-sustainable infrastructure. I also emphasized that sustainable investment is not directly observed. This is the reason various organizations have undertaken the herculean task of constructing measures of quality infrastructure. These indices typically range between zero and one or between zero and one hundred and synthesize many other indicators.

In this study, two such indices are used: *The Quality Infrastructure for Sustainable Development* (QI4SD) Index (https://hub.unido.org/qi4sd/) and the *Global Quality Infrastructure Index* (GQII) (https://www.gpqi.org/quality-infrastructure/articles/what-is-quality-infrastructure.html). In this section, these two indices are first defined and then their descriptive statistics are presented.

The Quality Infrastructure for Sustainable Development (QI4SD) Index

The QI4SD index is developed by the United Nations Industrial Development Organization (UNIDO) in collaboration with partner organizations of the International Network on Quality Infrastructure (INetQI). The index is used to compare the level of Quality Infrastructure (QI) to support the UN's Sustainable Development Goals (SDGs). Figure 5 shows the conceptual framework of the QI4SD, and in Appendix Table A1, all the indicators used to construct the overall index are provided, with Table 1 presenting summary statistics.

Figure 5. *Conceptual Framework of the QI4SD Index*



Source: https://hub.unido.org/qi4sd/about.

Each of the five dimensions consists of several indicators listed in Table A1 in the appendix. Data are available for 135 countries. These data are then used to ascertain the association between QI and the level of economic development of a country, as the latter is measured by the per capita GDP and population retrieved from the database of the International Monetary Fund (IMF).

Each dimension has an overall score from 0 to 100, and they are broken down into three different categories: social (people) index, environment (planet) index,

and an economy (prosperity) index, with the exception of the policy dimension, in which case only an overall evaluation is available.

Table 1 provides summary statistics of all the dimensions and their breakdown into social, environment, and economy. This illustrates the high dispersion in the scores of the various indicators. However, in this study, only the overall index of quality infrastructure is used.

Table 1. *Summary Statistics of the Various Indicators*

		Average	Maximum	Minimum	Standard Deviation	Total Countries
1	QI4SD index	37	88	7	20	135
2	Standards	43	89	6	18	135
3	Conformity	13	77	1	17	135
4	Metrology	29	92	1	23	135
5	Accreditation	47	100	1	38	135
6	Policy	80	100	35	18	61
7	People index	27	98	1	24	135
8	Planet index	26	96	1	24	135
9	Prosperity index	26	92	1	24	135
10	People Standards	36	100	1	28	135
11	People Conformity	18	100	1	26	135
12	People Metrology	17	100	1	27	135
13	People Accreditation	37	100	1	34	135
14	Planet Standards	32	99	1	26	135
15	Planet Conformity	18	100	1	27	135
16	Planet Metrology	16	100	1	27	135
17	Planet Accreditation	36	100	1	33	135
18	Prosperity Standards	31	98	1	25	135
19	Prosperity Conformity	20	100	1	27	135
20	Prosperity Metrology	21	100	1	27	135
21	Prosperity Accreditation	33	100	1	31	135

The summary statistics of this overall index are presented in Table 3. Table 2 shows the geographical distribution of the countries included in this index. This is based on the World Bank classification of countries and is adopted here. However, in the next index, the strict geographical definition of the countries is applied. The empirical results are not sensitive to this difference in classification.

Table 3 provides the descriptive statistics of the three variables used in the empirical analysis. The minimum value of the index is 6.8, and the maximum is 87.57. It is not 100 because no country has 100 in all indicators. The average is 37.41, and the standard deviation is 20.31 percentage points. The median of 34.19 is not much different from the mean, and the measures of skewness and kurtosis show that the distribution of the index is close to a normal distribution. High

skewness is evident in the distributions of per capita income and population. There are large variations in per capita GDP and population, with an average of $28,323 and 53.46 million people, respectively.

Table 2. *Geographical Distribution of the Countries Included in the QI4SD Index*

Region	**Number of Countries**	**Percentage of Total**
Sub-Saharan Africa	27	20%
East Asia & Pacific	15	11%
Europe & Central Asia	46	34%
Latin America & Caribbean	22	16%
Middle East & North Africa	16	12%
North America	2	1%
South Asia	7	5%
Total	**135**	**100%**

Table 3. *Summary Statistics of the QI4SD Index*

Statistic	**QI4SD Index**	**Per Capita GDP (US$)**	**Population (in millions)**
Mean	37.41	28323	53.46
Median	34.19	19295	10.85
Standard Deviation	20.31	25427	173.69
Kurtosis	-0.84	3	52.57
Skewness	0.42	2	7.04
Range	80.77	131663	1409.42
Minimum	6.80	809	0.10
Maximum	87.57	132472	1409.52
Countries	135	135	135

The Global Quality Infrastructure Index (GQII)

This index was initiated by the German Federal Ministry for Economic Affairs and Climate Action in collaboration with many national and international organizations, including the European Union. More information on the methodology of this index can be found at https://www.gpqi.org/about-the-project.html. As stated on their website, "The EU's legal framework and approach to quality infrastructure form the basis for Germany's position in the dialogues." As we shall demonstrate in the empirical section of this paper (Section Five), this might be the reason why the regression results show that only the dummy variable "Europe" was statistically significant, indicating that these countries share a common policy approach to quality infrastructure. "Common" here should be interpreted as meaning obligations and, of course, a common fund for financing such projects at the European level. Even European countries that are not members of the European Union benefit from such funding opportunities.

The conceptual framework of the GQII measurement is depicted in Figure 6. It is very similar to the previous index. This index includes more countries, totaling 184, compared to the 135 countries included in the previous index. The

geographical distribution of the countries included in this index is provided in Table 4.

Figure 6. *Conceptual Framework of the GQII Measurement*

Source: https://www.gpqi.org/quality-infrastructure/articles/what-is-quality-infrastructure.html.

Table 4 can be compared with Table 2, even though the classification is different; however, we retain the one suggested by the organization that developed this index. Countries from Africa account for 28% of the total, those from Asia for 24%, one-fourth of the countries were European, North America and South America represented 9% and 10%, respectively, and Oceania accounted for 4% of the total countries included in the sample.

Table 4. *Geographical Distribution of the Countries Included in the GQII Index*

Continent	Number of Countries	Percentage
Africa	51	28%
Asia	44	24%
Europe	46	25%
North America	17	9%
Oceania	8	4%
South America	18	10%
Total	184	100%

Table 5 provides summary statistics of the three variables. The average value of the index is 0.547, with a minimum value of 0.168 and a maximum of 0.994. It's worth noting that the values of the index range from zero to one. The mean value of per capita GDP is $17,196 thousand, and the population is about 4.3 million people.

Table 5. *Summary Statistics of the GQII 2023 Index*

Statistic	GQII 2023	Per Capita GDP (US$)	Population
Mean	0.547	17196	43239777
Median	0.508	6673	9918412
Standard Deviation	0.239	25824	153052634
Kurtosis	-1.206	12	71
Skewness	0.324	3	8
Range	0.826	183845	1428588079
Minimum	0.168	238	39584
Maximum	0.994	184083	1428627663
Countries	184	184	184

Source: Raw data were retrieved from https://gqii.org/gqii-2023/. Population is for 2023. The most recent (2022 or 2021) per capita GDP was used.

Empirical Evidence

The aim of this study is to demonstrate the association between quality infrastructure, per capita GDP, and population. We assume causality, with most economists agreeing that the causal relationship runs from output and population to quality infrastructure. The latter is considered a special type of investment with characteristics aligning with the Sustainable Development Goals (SDGs) set by the UN.

The accelerator model of investment in economic analysis establishes investment as a function of output, providing a theoretical foundation for the assumed causality. Additionally, we test the possibility that this relationship may not be linear. For the purposes of this empirical approach, we chose a quadratic functional form, nesting both hypotheses to be tested: the positive or negative effect of per capita GDP and population. This effect may vary and could depend on the level of per capita income and population. Furthermore, the marginal changes may not be consistent and could be influenced by income and population levels.

While many regressors were included in the empirical equation, only statistically significant coefficients are reported here. Table 6 presents the regression results with the dependent variable being the two quality infrastructure indices. The coefficient of determination is 53.17% for the first regression and 62.32% for the second. This indicates that the variations in the right-hand variables account for 53.17% and 62.32% of the variations in the quality infrastructure index. The F-statistic further indicates that all coefficients of the independent variables, as a group, are statistically significant.

In both indices, it was found that the same variables were statistically significant. Only the dummy variable "Europe" was statistically significant in the two regressions. The estimates for the other geographical dummy variables, which were not statistically significant, are not reported in the table. Why is Europe different? One obvious explanation might be that Europe has been pursuing policies at the European level, utilizing institutions such as the European Union

and the Eurozone to promote quality infrastructure. There are no analogous institutions in other countries around the world, where each country follows its own policies. However, this intriguing analysis extends beyond the scope of this study.

Table 6. *Regression Results*

Quality Infrastructure Index **Variables**	**QI4SD** (mean=37.4979)	**GQII** (mean=0.5466)
Constant	12.56 (6.76)	0.33 (20.34)
Per Capita GDP (Y) in 000s	0.7993 (5.96)	0.0090 (8.65)
Per Capita GDP (Y) in 000s squared	-0.0051 (4.67	-5.9E-05 (9.28)
Population (N) in millions	0.1807 (5.55)	0.0025 (6.73)
Population (N) in millions squared	-0.0001 (4.59)	-1.46E-06 (5.75
Dummy: Europe	11.27 (2.98)	0.19 (6.59)
R^2 Adjusted	0.5317	0.6232
F-Statistic	31.43	61.54
Number of Observations (countries)	135	184

Note: Absolute values of t-statistics in parentheses.

In both regressions, the effects of per capita GDP and population exhibit consistent signs. It's worth noting that per capita GDP is measured in thousands of dollars and population in millions of people. Although the two indices have different scales, this doesn't affect the sign of the parameters and the elasticity. However, it does make it initially challenging to compare the magnitude of the marginal effects due to the scale differences of the quality infrastructure.

Per capita GDP shows a positive effect, as expected, indicating that quality infrastructure increases with per capita output. However, the squared term is negative, suggesting that this increase occurs at a decreasing rate. As income rises, countries can allocate more funds to quality infrastructure, but there's an upper limit beyond which the effect turns negative. Mathematically, it's possible for the squared term's effect to dominate the linear effect of per capita output, resulting in an overall negative effect. This occurs if and only if:

$$\beta_1 + 2\beta_2 Y < 0$$

By substituting the estimated values for the coefficients in the regression model of QI4SD, we can determine the threshold value of per capita income at which its effect becomes negative:

$$0.7993 - 0.01Y < 0 \Longrightarrow Y > 0.7993/0.01 \Longrightarrow Y > 78{,}363 \text{ US\$}$$

Similarly, we can calculate the income effect in the regression model that uses the GQII as the dependent variable:

$$0.0090 - 0.000118Y < 0 \Longrightarrow Y > 0.000118/0.0090 \Longrightarrow Y > 76{,}271 \text{ US\$}$$

The similarities between these two numbers are striking, despite being derived from different methodologies for measuring quality infrastructure and different country samples. Given that these values represent critical turning points from positive to negative effects on quality infrastructure, one could argue that optimal quality investment occurs around these thresholds.

A similar analysis can be applied to estimate the effect of population. Larger countries invest more in quality infrastructure but at a decreasing rate. This is intriguing as it may suggest economies of scale based on population size. More people mean more potential users, making quality investment more beneficial. What, then, is the optimal population size for the two indices?

For the QI4SD index: $0.1807 - 0.0001N = 0 \Longrightarrow N = 0.1807/0.0001 \Longrightarrow$
$N = 1807$ millions of people

For the GQII index: $0.0025 - 0.00000146N = 0 \Longrightarrow N = 0.0025/0.00000146 \Longrightarrow$
$N = 1712$ millions of people

Once again, the outstanding similarity between the results highlights that the two different methodologies of data collection for constructing a quality infrastructure index and the diverse country samples did not impact the outcomes. However, the figures of 1.8 and 1.7 billion people lie beyond the current population range of any single country. This suggests that, concerning population levels, there is a desire for more quality infrastructure.

Table 7 presents the marginal effects and elasticities evaluated at the average values of the two indices, per capita GDP, and population. As anticipated from the preceding analysis, all marginal effects are positive when evaluated at the mean values. However, what holds particular interest here is the elasticity of income per GDP and population on the demand for quality infrastructure.

The elasticities are unit-free numbers and comparable across samples. Given that the marginal effects are positive, all elasticities must also be positive. The elasticities of the GQII index are lower than those of the QI4SD. A 10% increase in per capita GDP increases the quality infrastructure by 3.86% in the first index and 2.19% in the second index. Similarly, a 10% increase in population raises the quality infrastructure index by 2.42% in the first case and 1.88% in the second case.

These empirical results align with economic theory expectations. The estimates obtained fall within the range of values predicted by economic theoretical analysis. However, it's important to note that these evaluations are conducted at the average values of all variables. They provide insights into the long-term trajectory of the effects of per capita GDP and population on quality infrastructure but do not address short-term effects at the country level. Some aspects of these important issues are discussed in the final section of this study.

Table 7. *Marginal Effects and Elasticities*

QI Index	Variable	Marginal Effect Evaluated at Mean Values	Elasticity Evaluated at Mean Values
QI4SD (mean=37.4979) (countries=135)	Per Capita GDP in 000s (mean=28.32)	0.51	0.386
	Population in Millions (mean=53.46)	0.17	0.242
GQII (mean=0.5466) (countries=184)	Per Capita GDP in 000s (mean=17.20)	0.007	0.219
	Population in Millions (mean=43.24)	0.002	0.188

As an example, we use the above findings to analyze one country, Greece, to determine whether it is an underperformer or overperformer compared to the other 183 countries used in the estimation of the second index. According to the GQII index, Greece obtained a score of 0.8253 in 2023, ranking 38th in the world. It's important to ascertain whether, given Greece's per capita GDP, population, and its status as a European country, it could achieve better performance, or if its score exceeds what the model would predict. The equation for Greece is as follows:

$$QI_{GR} = \beta_0 + \beta_1 Y_{GR} + \beta_2 Y_{GR}^2 + \beta_3 N_{GR} + \beta_4 N_{GR}^2 + \beta_5 EUROPE$$

Substituting the estimated parameters, we obtain:

$$QI_{GR} = 0.33 + 0.009 Y_{GR} - 0.000059 Y_{GR}^2 + 0.0025 N_{GR} - 0.00000146 N_{GR}^2 + 0.19*(1)$$

The per capita GDP of Greece was $20.73 thousand USD, and Greece's population was 10.52 million people. Substituting these numbers, we obtain:

$$QI_{GR}=0.33+0.009*20.73 - 0.000059*430 + 0.0025*10.52 - 0.00000146*111 + 0.19$$

The estimated score for Greece is:

$$QI_{GR} = 0.7074$$

The score reported by the GQII index is 0.8253, a difference of 0.1179 points or 16.67% higher. Thus, Greece is performing better than what would have been predicted by its per capita GDP and population alone. Additionally, Greece being European adds 0.19 points to the index.

Using the other index (QI4SD), which includes fewer countries (135), Greece is performing better than expected by 7.74%. The score reported by the index for Greece is 49.84. The expected score given Greece's per capita GDP and population is 46.26, a difference of 3.58 units.

Discussion and Conclusions

Are there any policy implications for national or international authorities? The evidence indicates that quality infrastructure increases with income, but there is an upper limit of less than $80,000 per capita GDP in US dollars. This suggests that priority should be given to raising per capita GDP, as presumably this would enable relatively less affluent countries to allocate more funds toward quality infrastructure. Population does not present a bottleneck. The evidence shows that there are still economies of scale to be realized, and the existing quality of infrastructure can accommodate more people than it currently does.

Overall, indices serve as valuable benchmarks, and national governments and other authorities can utilize them to not only enhance the quality of infrastructure but also to improve the evaluation process of what is beneficial for a country given its current per capita GDP, population, and other characteristics. This assumes, of course, that when policymakers face a dilemma between infrastructure and quality infrastructure, it's because the latter is typically more expensive than the former.

Many policymakers, governments, and lobby groups argue that there exists a difference between the social and private (profit-oriented) rates of returns for infrastructure and quality infrastructure. However, measuring social rates of returns is no easy task, and methods such as contingency evaluation methods are subjective and may not accurately reflect the true preferences of citizens. Additionally, considering that public investment projects are often burdened with corruption, there is a pecuniary incentive for those involved in illegal activities related to these projects to lobby in favor of overestimating the social rates of returns.

The evidence presented here could provide guidance to policymakers. Quality infrastructure, however it may be defined, has an upper limit determined by a country’s per capita GDP and population size. The evidence for Greece, as demonstrated in this study, offers two interpretations. One is that Greece is an overperformer because it allocates more resources to quality infrastructure than expected given its per capita GDP, population, and status as a European country. The second interpretation could be that Greece is spending more (or possibly wasting) public funds to achieve higher quality infrastructure than necessary. These limited public resources might have been better utilized in smaller, more focused projects with higher social rates of return. Further research is necessary to illuminate this important issue not only for Greece but also for other countries.

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Appendix

Table A1. *List of Indicators in the QI4SD Index - General Indicators (G) and 3P Indicators (P) in the Framework*

Dimension	Name	Description	Unit	Organization	Type	Weight
Accreditation	Scopes of IAF accreditation bodies	Number of scopes for the IAF Multilateral Recognition Arrangement mapped into the 3Ps.	Number	IAF	P	1
	Signatory to the IAF MLA	Existence of an accreditation body that is a signatory to the IAF Multilateral Recognition Arrangement.	Yes/no	IAF	G	1
	Scopes of ILAC accreditation bodies	Number of scopes for the ILAC Mutual Recognition Arrangement mapped into the 3Ps.	Number	ILAC	P	1
	Signatory to the ILAC MRA	Existence of an accreditation body that is a signatory to the ILAC Mutual Recognition Arrangement.	Yes/no	ILAC	G	1
Conformity	Membership of IEC conformity assessment systems	Country membership in the four IEC conformity assessment systems (IECEE, IECEx, IECRE, IECQ), range 0 to 4.	Number	IEC	G	1
	Number of IECEE certificates recognised	Number of IECEE certificates present in country.	Number	IEC	G	1
	Number of recognised certificates (IQNet)	Number of recognised certificates from IQNet database mapped into 3Ps.	Number	IQNet	P	0.5
	Membership of IQNet	Level of involvement in IQNet, location of head, subsidiary offices and origin of Certification Bodies.	Composite score	IQNet	G	1
	Number of recognised certificates (ISO)	Number of recognised certificates from ISO database mapped into 3Ps.	Number	ISO	P	0.5
Metrology	Participation in CIPM Consultative Committees	Sum of overall participation in ten Consultative Committees, range 0 to 20.	Number	BIPM	G	1
	Participation in key and supplementary comparisons	Sum of the scores for the key and supplementary comparisons.	Number	BIPM	G	1
	Number of CMCs	Total number of Calibration and Measurement Capacities (CMCs) in any area mapped into 3Ps.	Number	BIPM	P	0.5
	Breadth of CMCs	Total breadth of Calibration and Measurement Capacity (CMC) types with at least one capacity mapped into 3Ps	Number of types	BIPM	P	0.5
	Membership of BIPM	Membership of BIPM, range 0 to 2.	Categorical	BIPM	G	1
	Membership of OIML	Membership of OIML, range 0 to 2.	Categorical	OIML	G	1
	OIML-CS - number of services offered	Number of OIML Certification System (CS) services offered.	Number	OIML	G	0.5
	OIML-CS - number of services recognised	Number of OIML Certification System (CS) services recognised.	Number	OIML	G	0.5
	Involvement in OIML project groups	Number of project groups for which each country is a convener (C), participating member (P) and observer (O).	Composite score	OIML	G	1
Policy	Participation in capacity building programmes	Participated in capacity building programmes related to QI from BIPM, OIML, ISO, WTO in the last two years, range 0 to 4.	Number of types	UNIDO/ISO	G	1
	Quality Policy in place	National or regional Quality Policy in place, a policy for developing and sustaining effective QI.	Yes/no	UNIDO/ISO	G	1
	Dimensions of QI addressed by Quality Policy	QI dimensions (Metrology, Standards, Accreditation, Conformity Assessment) addressed by the Quality Policy or regulatory framework, range 0 to 4.	Number	UNIDO/ISO	G	1
	Support and funding for Quality Policy	Governmental support, including funding, stipulated in the Quality Policy or in the regulations and directions supporting QI.	Yes/no	UNIDO/ISO	G	1
	Government/political endorsement for Quality Policy	Development and implementation of the Quality Policy being endorsed by the political level or led by the highest level of government.	Yes/no	UNIDO/ISO	G	1
	Government approval of Quality Policy	Quality Policy approved by government or regional country grouping.	Yes/no	UNIDO/ISO	G	1

	Stakeholder involvement of Quality Policy	Involvement of stakeholders from the private and public sectors, consumers, producers in the Quality Policy process.	Yes/no	UNIDO/ISO	G	1
	Consideration of diversity in Quality Policy	Gender balance and other diversity aspects considered in the Quality Policy process.	Yes/no	UNIDO/ISO	G	1
	Implementation plan for Quality Policy	Presence of implementation plan for the national Quality Policy, i.e. a plan that sets out the steps for achieving the policy objectives.	Yes/no	UNIDO/ISO	G	1
	Monitoring and evaluation for Quality Policy	Mechanism(s) for monitoring and/or evaluating the implementation/outcomes of the Quality Policy.	Yes/no	UNIDO/ISO	G	1
	Reviewing and updating for Quality Policy	Mechanism(s) for periodically reviewing and updating the Quality Policy.	Yes/no	UNIDO/ISO	G	1
Standards	Adopted ISO standards	ISO standards that had been adopted into national legislation and mapped into the 3Ps.	Number	ISO	P	1
	Adopted IEC standards	IEC standards that have been adopted and mapped into the 3Ps.	Number	IEC	P	1
	Membership of IEC	Membership of the IEC, range 0 to 3.	Categorical	IEC	G	1
	Participation in IEC technical committees	IEC technical committees (TCs) participation mapped into the 3Ps.	Number	IEC	P	1
	Membership of ISO	Membership of the ISO, range 0 to 3.	Categorical	ISO	G	1
	Participation in ISO technical committees	ISO technical committees (TCs) participation.	Number	ISO	G	1
	Membership of ITU	Composite score of membership of ITU.	Composite score	ITU	G	1

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Layout Characteristics and Design Principles of Atrium Integrated Space

By Shaoming Lu[*]*, Xiujie Li*[±] *& Zheng Tan*[°]

With the development of China's cruise tourism industry, it is necessary to study the design and construction of cruise ships, especially the central atrium, which is an important part of public area design and represents the quality and characteristics of the entire ship's design. However, compared with Europe, China's research foundation for large-scale cruise ship design is still lacking. Therefore, studying the spatial layout characteristics of the central atrium is of great significance for improving China's cruise industry. This article focuses on the design principles and characteristics of integrated space layout in the central atrium of cruise ships. By applying basic theories from architecture, shipbuilding engineering, aesthetics, international maritime safety conventions and technology to analyzing representative central atria from 25 typical domestic and foreign cruise brands through data collection and research methods including mathematical statistics methodology, clustering methodology and cases research methodology. Through comparison and generalization of the cases, the study eventually summarizes six overall principles and four structural principles for designing integrated space in the central atrium of a cruise ship. The six overall principles include safety, rationality, applicability, artistry, coordination and technique-economics. The four structural principles include clear space circulation, natural spatial connection, theme coordination & unification and prominent key levels. This study provides insights into designing integrated space in the central atriums of cruise ships that hopefully can be applied in improving China's cruise design work while also supporting guidance for future related fields.

Keywords: *central atrium of cruise ship, integrated space, design principles, functional layout, decoration style*

Introduction

Research Background

In recent years, the development of cruise tourism in China has attracted more and more attention. Europe has now developed into the world's leading cruise design and production base (Huang 2018, Qian 2021). However, Asia is still in a backward state. In particular, compared with Europe, China's cruise design lacks the research foundation for large-scale cruise design. China's cruise industry still

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has many deficiencies in industrial planning, cruise design, cruise service system, cruise consumption concept and other aspects (Wang 2019).

The design and construction of cruise ships is the crystallization of cooperation between cruise ship design and architectural art design. The traffic area of the cruise is an important part of the public area design, which directly reflects the quality and characteristics of the whole ship design and the characteristics of traffic space layout are the basis of traffic area design. As an important node of traffic space, the atrium is highly integrated in many aspects such as working function, interior assembly and theme representation. Therefore, it is of great significance to study its spatial layout characteristics.

Research Content

This paper studies the cruise ship atrium. Cruise ships originally refer to large passenger ships with fixed routes and regular voyages at sea. At present, cruise ships in academia and industry refer to luxury ships that are mainly sailing at sea, equipped with relatively complete living and entertainment facilities, and specially used for tourism, leisure and vacation. For tourists, the cruise itself is one of the tourist destinations, and enjoying various facilities and services on the cruise is a major part of marine tourism (China Classification Society 2017).

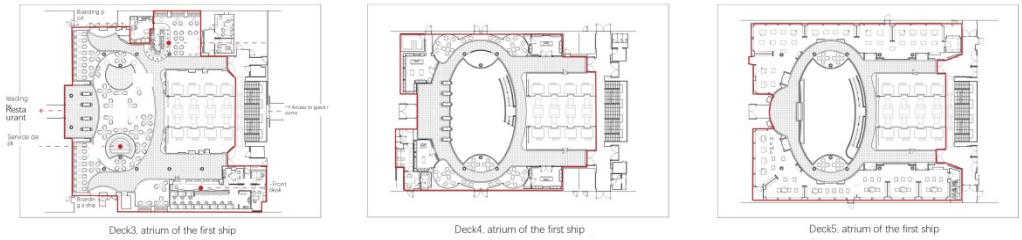
Today, cruise ships have gradually transformed from traditional postal and transportation functions into movable waterborne buildings with tourism and entertainment as the main content, which have the basic characteristics of buildings. However, due to the particularity of ships, cruise ships, compared with onshore buildings, have their unique artistic features and design specifications (Coufer and Oil, E. I. C. E. Inter-Governmental Maritime Consultative Organization 1974).

The traffic area is an important part of the key technology of cruise public space, and the design of the traffic area also directly reflects the quality and characteristics of the whole ship design, which is an important part of the public area design. As a landmark node in the public space and a hub node in the traffic space of the cruise ship, the cruise atrium naturally has integrated spatial characteristics. The cruise atrium is the node space of the traffic space. On the one hand, the cruise atrium creates a first impression for tourists to perceive the cruise ship and is an important place for tourists to experience the identifiability of the cruise ship; On the other hand, the cruise atrium is the core area presenting the cruise theme culture, and the design of the cruise atrium directly affects the comprehensive competitiveness of the cruise and the satisfaction of tourists.

Specifically, the cruise atrium refers to the public area connecting the main corridor, stairs, elevators and other spaces inside the cruise ship. The reason why it is called the atrium integrated space is that it meets the demands of the integration of multiple functions, comprehensive transportation and various information; Functions include lobby, rest, reception, registration, business, exhibition, assembly, social shopping, performance and other functions. The traffic involves vertical flow of people (elevators), horizontal flow of people (walkways, ring corridors), indoor and outdoor flow of people (external decks and indoor gatherings). For example, the atrium of the first large-scale cruise ship in China has multiple

functions such as boarding reception, front desk service, shopping, catering, social entertainment, and rest. The atrium is close to the bow elevator hall, connects the restaurant and guest room area, and connects the indoor space and outdoor deck. It is an important public space for tourists' entertainment, leisure, and consumption experience, and also a transportation hub to meet the demand for evacuation, assembly, and other distribution functions of passenger flow (Figure 1).

Figure 1. *Research Scope*



Source: Author.

Atrium is an ancient architectural space form. According to the Oxford Dictionary, it refers to the central courtyard in Roman times, usually with a covered cloister, mainly located in the front of the church entrance.

According to the Royal Geographical Society, the atrium refers to a roofed courtyard within or between buildings, usually with several levels, which serves as the central point of arrival and circulation (Saxon 1983).

According to the ancient Chinese literature, the atrium is the middle part of the front steps of the ancient temple, where officials stand when the court meets or confers nobility. In Guanzi · Zhongkuang, it is recorded that: "Guan Zhong returned and leaned against the screen, and the king refused to talk; Then Guan Zhong took a few steps into the atrium, and the king still refused to talk." It is also recorded that the atrium is the central space of the hall, or the open courtyard in the center of the building. In Shanglin Fu written by Xiangru Sima in Han Dynasty, it is recorded that "Sweet water springs out in the tiny room, and free streams flow through the yard."

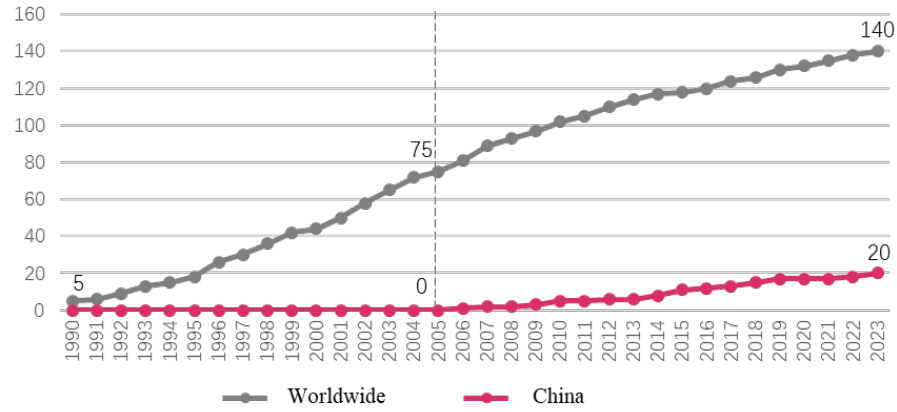
In nowadays, the atrium is endowed with more functional values. It is widely used in public buildings such as hotels on land and cruise ships on the sea. It is a large hall with lobby, rest, reception, registration, business and other functions (Psarra 2021). The function of the atrium space includes: sharing the space of the external environment for the internal environment of the building; Experiencing natural light - "outdoor space" in the interior; Providing space for sense of direction and helping users overcome negative psychological reactions.

Literature Review

Up to now, the existing research of cruise ship atrium is still quite lacking at home and abroad. According to WOS and Google Scholar, in the latest 30 years there are only 32 literatures on the subject of “cruise ship atrium” published in

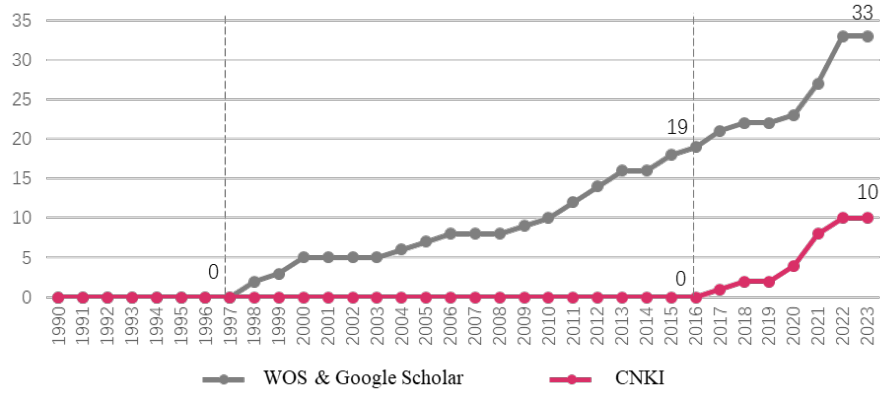
total worldwide, while at the same time over 140 new cruise ships have been put into service. The research in similar fields in China just starts and devotes 10 related literatures (Figures 2-3).

Figure 2. *Total Amount of New Cruise Ship since 1990*



Source: Author.

Figure 3. *Total Amount of Literature on the Subject of 'Cruise Ship Atrium'*



Source: Author

The existing researches have explored many valuable methods for cruise atrium design from the perspective of different professional fields, but there are some limitations at the same time. For one thing, the existing research on cruise ship atrium mainly focuses on construction practical technique (Wieslaw 2012) and influence on Business Models & Revenue (Kulhanek 2012), while there are few studies analyzing the atriums` interior assembly and influence on activities. On the other hand, the existing research from the perspective of architectural & interior design mainly analyzes directly based on certain specific element like enclosure of atriums (Xi and Chen 2022), but few studies provide a preliminary systematic composition structure of cruise ship atriums to obtain an overall understanding. Therefore, a systematic analysis framework of cruise ship atrium based on spatial features and scientific principles for the spatial layout design are the two key points to be solved in the research field of cruise ship atrium.

The purpose of this research is to collect, analyze and summarize the cases of the typical cruise ship atrium space at home and abroad, sort out the development context and rules of the cruise ship atrium space layout at home and abroad, reveal and summarize the evolution rules, design principles and strategies of the cruise ship atrium space design, so as to fill the gap in the research on the cruise ship atrium space layout in domestic academia. The research further provides basic data and theoretical methods for the optimization scheme of cruise ship atrium space, and provides theoretical support and technical guidance for the independent design and construction of the first domestic cruise ship.

Methodology

This research uses data from multiple authoritative data sources, including the database of Shanghai Waigaoqiao Group, the official website of dozens of well-known cruise brand companies around the world, the official website of the famous international cruise industry organization - International Cruise Association, and combines Wikipedia data to conduct a comprehensive data collection and research on the cruise atrium space of representative cruise lines at home and abroad.

The study then uses mathematical statistics methodology, clustering methodology, case research methodology and other methods to study the spatial layout characteristics of the atrium as a node integrated space in the cruise traffic space. With the first ship as the key research object, the study analyzes the three main elements of spatial form (components), structure and functional layout, sorting out the characteristics and evolution mechanism of modern cruise ship atrium integrated space layout in the past 30 years. Then the study focuses on the core issues of the traffic area-visibility and accessibility-for analysis and optimization.

This study uses inductive and deductive methods to summarize the basic principles and techniques of cruise atrium integrated space design, sort out the basic laws, and then summarize the design principles and strategies of cruise atrium integrated space as a traffic node.

Results

Atrium Integrated Space and its Constituent Elements

As a central organization space for passenger service with wide adaptability, strong accessibility and high relevance in cruise ships, the atrium is an important space for daily and random communication of tourists in the cruise public space, and also a critical node in the transportation space of large cruise ships, and has the characteristics of integration and economy (Guan 2015).

The integrated space of cruise atrium includes three main elements: spatial form, interior assembly and functional layout.

Among them, spatial form is the existence form of space as a matter, which is mainly reflected by the scale, proportion, shape, division, enclosure and other

elements of space (Deforge and Cullars 1990). The cruise ship atrium is composed of deck, bulkhead, canopy, furniture, etc. Its spatial form is mainly reflected in the distribution type, location distribution, planar form, interface form, spatial scale, etc. (Barry 2006).

The interior assembly refers to the interrelationship and distribution characteristics between the various parts of the space inside the atrium. Different types of interior assembly will shape different images of the atrium and bring different spatial experiences to tourists. The interior assembly design of the cruise ship atrium needs to consider the particularity of different spaces and the regularity, coordination, combination and other elements of multiple spatial associations, as well as the primary and secondary relationship of tourists' experience paths and spaces. The layout combination, people organization evacuation and circulation design of the cruise ship atrium are supposed to be conducted to meet the needs of the cruise theme and transportation hub, and achieve the goal of intensification (Sun et al. 2016).

The functional layout includes the planning and combination design of functional activities for the cruise ship atrium, which is an important design factor for the atrium as a node of public space (Tan et al. 2016). The functions undertaken by the atrium usually include the lobby, rest, reception, registration and business. The atrium space is closely connected with other surrounding spaces, including corridors, elevators, shopping spaces, restaurants and other public spaces. In the design of functional layout, it is essential to focus on the relationship of division and combination among various parts, and solve various contradictions one by one to achieve a reasonable and perfect functional relationship, a reasonable function arrangement, a vivid layout and a clear circulation. In addition, the functional layout should be combined with the spatial form and interior assembly of the atrium to meet the spiritual needs of tourists in the limited space and enrich the navigation life (Bruce 2006).

The research report will study the characteristics of integrated space layout of the cruise ship atrium, which is the most important public transport space node in cruise ships, based on the three elements of spatial form, interior assembly and functional layout described above, from the perspective of the scientific ship aesthetics. This research is also based on the comprehensive application of basic theories in architecture, shipbuilding and aesthetics, and the International Convention and Technology for the Safety of Life at Sea.

Spatial Form Characteristics of Atrium

The study compares the typical atriums of 15 typical cruise brands at home and abroad according to 5 different factors including distribution type, location distribution, plane shape, interface form, and spatial scale, and obtains the characteristics of the typical atriums of different cruise brands at home and abroad.

Spatial Form Characteristics of Atrium of Foreign Cruise Brands

(1) Distribution type

The distribution type of most cruise ship atriums abroad is centralized. The centralized distribution type atrium means that the atrium has become a large indoor shared space in cruise ships. The atrium integrates many functions, such as front desk service, business center, luggage service, tour consultation, bar catering, large gatherings, etc., creating a place full of life and humanity, just like an indoor city square. This is also the mainstream atrium distribution form adopted by foreign cruise companies such as Carnival Cruise Lines, Costa Cruise Lines, Princess Cruise Lines, Disney Cruise Lines, etc.

Decentralized distribution type atrium refers to that there is more than one atrium space on a ship, and different atriums have different spatial forms, decoration styles, functional themes, and play different roles. The distribution type of decentralized atriums in foreign cruise ships began in 2000. There are three types of atriums in Royal Caribbean International Cruise Lines, namely Royal Avenue, Central Park, and 270° landscape atrium, which are distributed in the middle and tail areas of the deck layer. The atrium design has its own characteristics. Royal Avenue belongs to the "linear atrium" form of Long Corridor Street. It is located in a ship with five decks and is more than four decks high, with a large spatial scale. The first and second floors of the atrium are public facilities such as shop, coffee and catering, front desk service, etc. The upper floor is the cabin space, and the top is glass and or art decoration. At the end of the Royal Avenue, a small atrium is usually set as the atrium for traffic and crowd flow. Central Park is the open comprehensive leisure area at the core of the whole cruise ship. It is rectangular in shape, generally located in the middle of the eighth deck, with six decks height, and has a large spatial scale. The bottom floor of the atrium is public entertainment facilities such as shopping, coffee and catering, and the upper five floors are the cabin space. The 270 ° landscape atrium, which has appeared since 2014, is semi elliptical in shape and is generally located at the stern of the fifth deck. It is enclosed by a huge floor glass wall spanning three decks. The enclosed interface is curved and inclined. It is a scientific and technological atrium integrating sightseeing, modern performance, rest and dining. In addition, the appearance of arcades in Mediterranean Cruise Lines since 2016 is also a decentralized atrium.

(2) Location distribution

The atriums of foreign cruise ships are distributed in various locations, from the first floor to the ninth floor. Before 1998, most of the atriums of foreign cruise ships were mainly distributed on the higher deck above the seventh floor. From 1995 to 2014, the distribution of the atrium began to move down to the lower deck, mainly concentrated on the third to fifth floor. From 1995 to 2013, the distribution of the atrium began to move up to the middle layer of the cruise ship, which is mostly the fifth or sixth layer. From the perspective of development trend, the distribution of atriums of foreign cruise ships in the future may be more concentrated in the middle layer (5-6 layers) of cruise ships.

From the vertical comparison between different foreign cruise lines, Carnival Cruise Lines and Costa Cruise Lines have various atrium locations, but the overall trend is downward; the atriums of Royal Caribbean International Cruise Lines are mainly located in the middle floor (4-5 floors) of the cruise ship. The atrium built in 2009 was located on the 8th floor because of the appearance of the central park atrium. Due to the nature of open space enclosure, its distribution position was on the upper floor. Other foreign cruise companies have relatively stable atrium locations, such as Princess Cruise Lines (4-5 floors), Mediterranean Cruise Lines (5-6 floors), Norwegian Cruise Lines (5-7 floors), Disney Cruise Lines (3 floors) and Cunard Cruise Lines (1-2 floors).

(3) Planar form

The planar form of most cruise ship atriums abroad is mostly circular and elliptical. From 1990 to 1998, the planar form of the atrium was mainly circular and elliptical; since 1998, the planar form of atrium has been rectangular, corridor shaped, and polygon, and has continued to this day. From 2010, the planar form of atrium began to appear irregular shape. From the perspective of development trend, the planar form of the atrium of foreign cruise ships in the future is more inclined to irregular free shape or the combination of multiple planar shapes.

From the perspective of comparison between different foreign cruise companies, those companies whose atriums' planar shapes are mainly circular (including ellipse and arc) include Princess Cruise Lines, Holland America Cruise Lines, Cunard Cruise Lines, Royal Caribbean International Cruise Lines before 1999, Norwegian Cruise Lines before 2007, and Mediterranean Cruise Lines before 2010. Cruise companies whose atriums' planar shapes are mainly rectangular (including those with nested circles or squares) include Carnival Cruise Lines and Disney Cruise Lines. The cruise companies with the planar shape of the atrium dominated by polygons include Costa Cruises. Since 2000, Royal Caribbean Cruise Line has been mainly in the form of atrium with long corridor "Royal Avenue". Since 2010, Norwegian Cruise Lines and Mediterranean Cruise Lines have started to use irregular atrium planes.

(4) Interface form

The atrium interface of most foreign cruise ships is mainly circular, curved and vertical enclosure. Since 2009, Royal Caribbean International Cruise Lines has appeared a new interface form of open air and inclined enclosure. From the perspective of development trend, the atrium interface form of foreign cruise ships in the future will be more inclined in curvature and freer style.

From the perspective of comparison between different foreign cruise companies, cruise companies that mainly adopt the form of vertical interface are: Carnival Cruise Lines and Disney Cruise Lines. Cruise companies that mainly adopt the form of round (including curve) interface include: Princess Cruise Lines, Mediterranean Cruise Lines, Norwegian Cruise Lines, Cunard Cruise Lines, Holland American Cruise Lines. Cruise companies that adopt a variety of encirclement methods

include Costa Cruise Lines and Royal Caribbean International Cruise Lines.

(5) Spatial scale

The space scale of the atrium of foreign cruise ships is diversified, ranging from a small scale of one floor in height to a super scale of over seven floors in height, but mainly is at a moderate scale of 2-3 floors in height. Before 2004, there were mainly two kinds of atriums in most foreign cruise ships: 7-storey high large-scale atriums and 3-storey moderate scale atriums. After 2004, the atrium scales are mainly at a moderate level of 3-4 floors in height. Since 2017, the sizes of atriums have become larger.

From the horizontal comparison between different foreign cruise companies, the atrium spatial scale law of most foreign cruise ships is basically consistent with the above. It is worth mentioning that the atrium space scale of Royal Caribbean International Cruise Lines is generally large, especially the atrium of the Brilliance of the Seas in 2002 is 7-storey high. In addition, the "Central Park" outdoor atrium space scale of the brand since 2009 is also large, spanning 6 stories.

Spatial Form Characteristics of Atrium of Domestic Cruise Brands

(1) Distribution type

The distribution type of atriums of all domestic cruise brands is basically centralized.

(2) Location distribution

The atriums of domestic cruise ships are mainly distributed at the fifth to the seventh floors. From 1988 to 1999, the atriums were mainly located in the upper layers of the cruise ship (over the seventh layer). From 2000 to 2017, the distribution of the atriums moved down to the middle of the cruise ship (at the fifth and sixth floors).

(3) Planar form

The planar form of domestic cruise ship atrium is mostly rectangular, and irregular planar form has appeared since 2010. Among them, the planar form of the atrium of Hong Kong Star Cruises is mainly rectangular and round (semicircle). Atriums of domestic cruise lines in China are mainly rectangular and irregular in shape.

(4) Interface form

The atrium interfaces of most domestic cruise ships are mainly vertical enclosure type. Since 2012, interfaces of cruise lines in mainland China have appeared in the form of curve interface.

(5) Spatial scale

The atrium space scale of domestic cruise lines is diversified and the annual distribution is relatively average, ranging from a small scale of one-floor height to a large scale spanning over 5 floors.

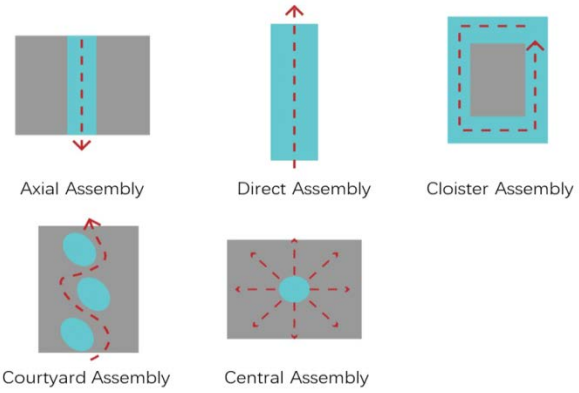
Interior Assembly Characteristics of Atrium

The spatial assembly characteristics of cruise ship atriums are closely linked to both the theme positioning of the ship and the spatial form of the atrium. This study, through the collection and pattern analysis of representative atrium decoration styles both domestically and internationally, has identified the typical characteristics of cruise ship atrium spatial assembly types (Figure 4).

Cruise ship interior assembly types can be categorized into linear assembly and focal point central assembly: Linear assemblies in cruise ship atriums often possess clearly defined linear sequences of movement and spatial guidance. Key spaces or primary paths form linear spatial cues, with secondary spaces arranged symmetrically, circumferentially, or dispersed freely around this main sequence. Depending on the relationship between these secondary spaces and the main traffic flow, linear assemblies can be further subdivided into axial assembly, direct assembly, corridor assembly, and courtyard assembly.

Focal point central assemblies in cruise ship atriums radiate outward from a unique central space, with other spaces distributed around this center. This center serves as a crucial node in design and the hub of tourist activities and experiences (Lu 2018).

Figure 4. *Interior Assembly Characteristics of Cruise Ship Atrium*

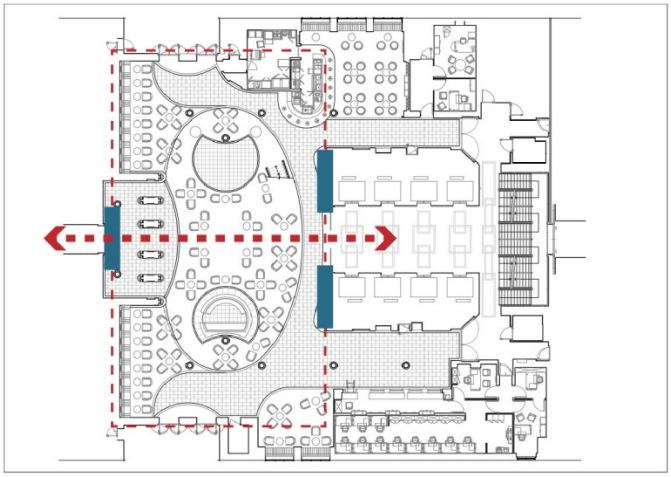


Source: Author.

Axial Assembly

In this type, key nodes or primary spaces within the cruise ship atrium form a distinct axis. The spaces and nodes on this axis also comprise the center of design, with other spaces symmetrically distributed around this axis. The atrium of the Adora Magic City serves as the representative example of this type of assembly (Figure 5).

Figure 5. *Interior Assembly of the Adora Magic City*

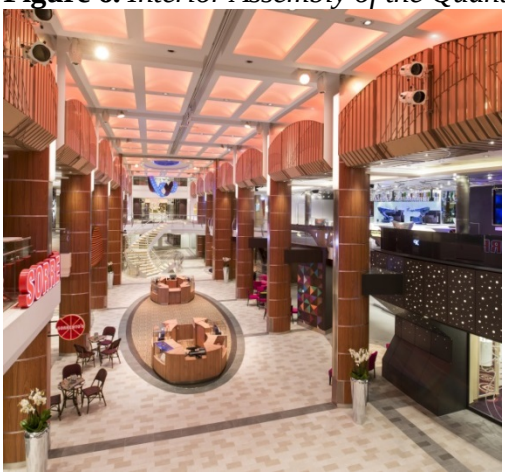


Source: Author.

Direct Assembly

This type means that all parts of the spaces in the atrium (the main platform, stairs, rest area, characteristic space, etc.) are arranged along a straight line, and the main circulation of tourists coincide with this. This type of atrium space is also dominated by the strip type, and the representative cruise ship atrium is the Quantum of the Seas' atrium "Royal Avenue", belonging to the Royal Caribbean International Cruise Lines (Figure 6).

Figure 6. *Interior Assembly of the Quantum of the Seas*



Source: https://oceanworldtravel.com/cruise-ship/.

Corridor Assembly

This type is characterized by the main spatial traffic flow of the atrium distributed in a corridor-like circular arrangement, commonly observed in the upper spaces of multi-story atriums, like the five-story space of the "Royal Promenade" atrium in the Royal Caribbean's Quantum of the Seas. The spaces around the corridor primarily focus on shopping and experiences and can also appreciate the

design of the atrium from an overlooking perspective (Figure 7).

Figure 7. *The Corridor on the Fifth Floor of the Quantum of the Seas' Atrium*

Source: https://oceanworldtravel.com/cruise-ship/.

Courtyard Assembly

In this format, the primary spaces within the atrium are organized in a relatively free manner within the constraints of linear boundaries, offering visitors a courtyard-like experience. The representative example of this type is the "Central Park" atrium of the Royal Caribbean's Wonder of the Seas. The boundaries of "Central Park" adhere to a regular rectangle, but its main internal space is a garden filled with green plants. The visitor's traffic flow meanders through it, combined with transparent daylight from above, providing the experience of an outdoor courtyard (Figure 8).

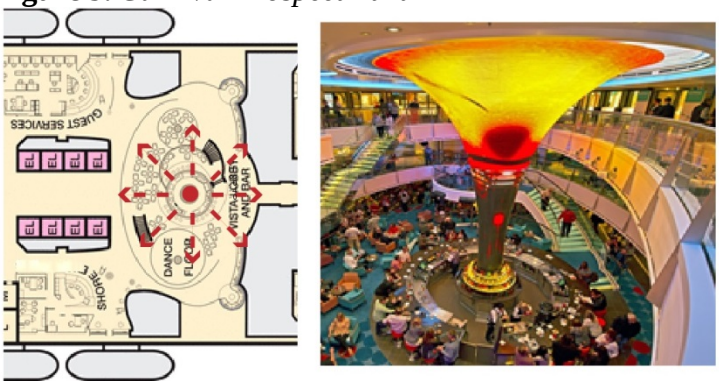
Figure 8. *Atrium Interior Assembly of Wonder of the Seas*

Source: https://oceanworldtravel.com/cruise-ship/.

Central Assembly

In this format, the primary spatial node of the atrium is the center of the atrium space, with the rest of the spaces, functions, and activities radiating divergently around this center. The representative example of this type is the atrium of the Carnival Vista (Figure 9).

Figure 9. *Carnival Prospect Atrium*



Source: https://oceanworldtravel.com/cruise-ship/.

Functional Layout Characteristics of Atrium

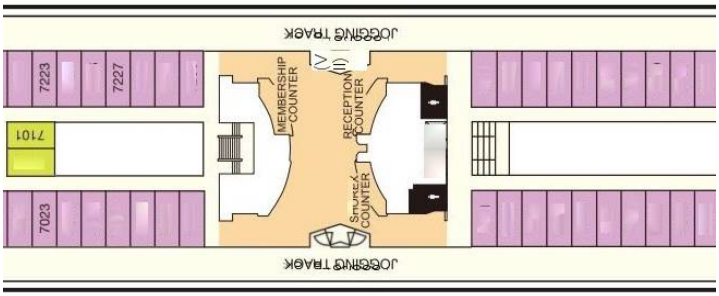
The study summarizes the laws and characteristics of the function layout of cruise ship atriums through research on the functional composition of the atrium itself and its adjacent area, and spatial layout of atriums from typical domestic and foreign cruise ship brands.

Research on Functional Layout of Cruise Ship Atrium

(1) Single-function type

This type refers to the atrium functions being limited to a single reception service and consultation office, without any entertainment functions. This type is less common in cruise ship atriums. The representative cruise ship of this type is the Aquarius Star belonging to Star Cruise Lines (Figure 10).

Figure 10. *Functional Layout of the Atrium of the Aquarius Star*



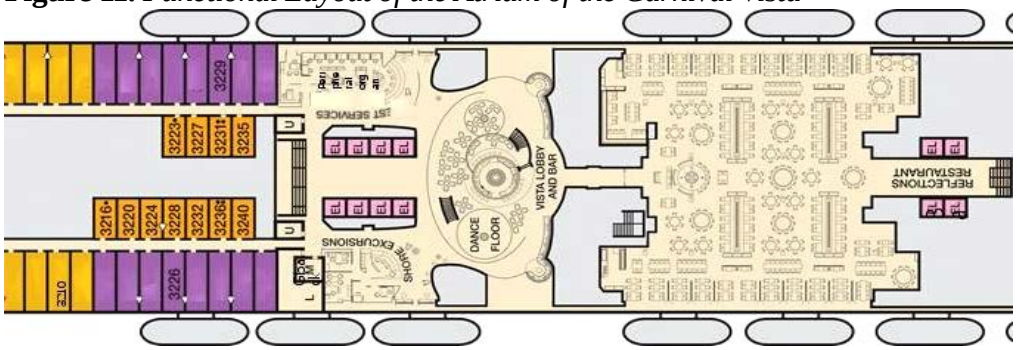
Source: Author.

(2) Multi-function Type

In this type, the atrium function group not only includes the reception service and consultation office but also includes dining, dances, and other entertainment functions. It can be further divided into three types: simple mixed type, comprehensive entertainment type, and spectator type. The simple mixed type refers to the atrium functions primarily serving as the reception and consultation

office, supplemented by functions such as bars, dining, and exhibitions. This type is more common in cruise ship atriums, represented by the Carnival Vista (Figure 11).

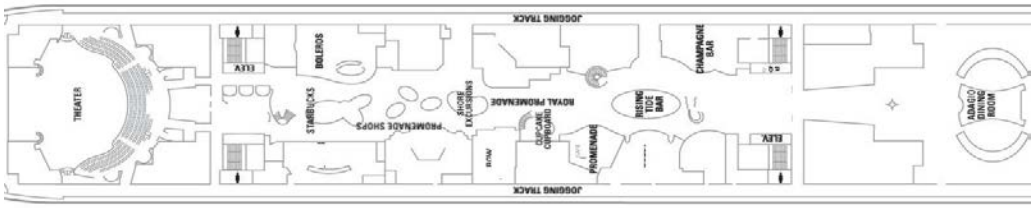
Figure 11. *Functional Layout of the Atrium of the Carnival Vista*



Source: Author.

The comprehensive entertainment type refers to the atrium serving as the core comprehensive leisure area of the entire cruise ship, with functions mainly based around entertainment, typically including bars, coffee, dining, shopping, performances, etc. This type primarily appears in the Royal Promenade atrium format of the Royal Caribbean International cruise ships, represented by the Harmony of the Seas (Figure 12).

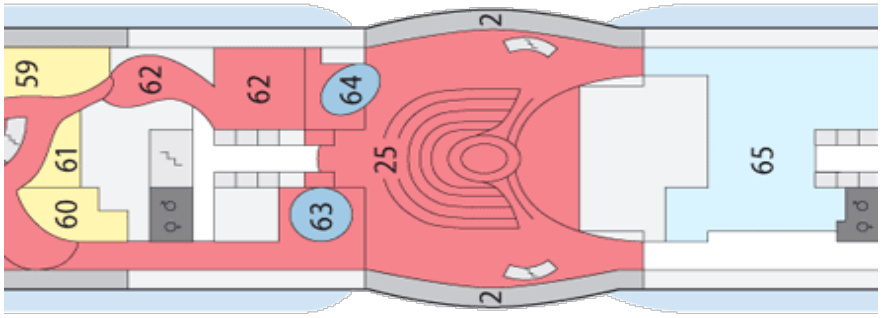
Figure 12. *Functional Layout of the Atrium of the Harmony of the Seas*



Source: https://oceanworldtravel.com/cruise-ship/.

The spectator type appeared from 2008 in the new atrium function types of AIDA Cruises, which is a combination of the functions of a lobby and a theater. The representative cruise ship of this type is the AIDA Prima (Figure 13).

Figure 13. *Functional Layout of the Atrium of the AIDA Prima*



Source: Author.

Research on Functional Layout of Adjacent Areas of Cruise Ship Atrium

(1) Cabin Adjacent Type

This type refers to the atriums whose adjacent area is dominated by cabins, which can be further divided into four types: type of cabins on both sides represented by the Carnival Inspiration; type of dining area on one end represented by Princess Cruises' Island Princess; type of surrounding cabins on four sides represented by the Royal Caribbean's Oasis of the Seas; type of cabins on the front end without the rear end represented by the Skysea Cruise's Golden Era in China (Figure 14).

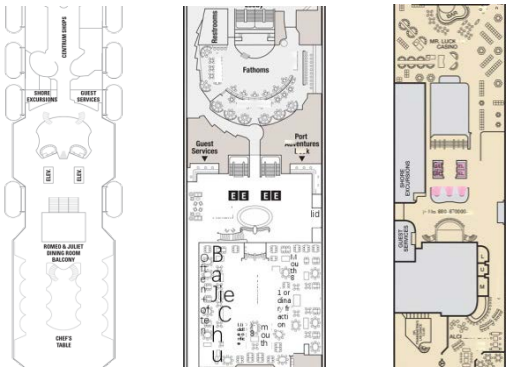
Figure 14. *Functional Layout of Atrium Adjacent Areas of the Carnival Inspiration (first from left), the Island Princess (second from left), the Oasis of the Seas (third from left), the Golden Era (first from right)*

Source: Author.

(2) Dining Adjacent Type

This category refers to the areas adjacent to the atrium, which are mainly composed of dining facilities, and can be subdivided into three types: The first is exemplified by the Royal Caribbean International's Legend of the Seas, featuring a front end with comprehensive functions (business center, shopping, theater, club, coffee, etc.) and a rear end designed for dining. The second type is represented by Disney Cruise Line's Magic, where both front and back ends are dedicated to dining. The third, epitomized by the Carnival Legend, has a dining-focused front end and an entertainment-focused rear end (Figure 15).

Figure 15. *Functional Layout of Atrium Adjacent Areas of Legend of the Seas (first from left), the Disney Magic (second from left) and the Carnival Legend (third from left)*

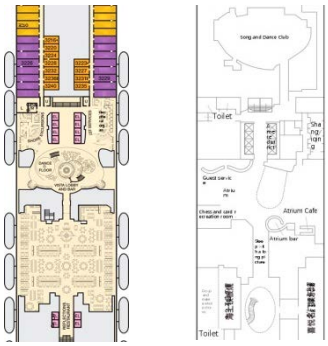


Source: Author.

(3) Mixed entertainment adjacent type

This type refers to the areas adjacent to the atrium, functioning as comprehensive zones, which can be further subdivided into those with promenade decks on both sides and those without. The atrium of the promenade deck type, represented by the Norwegian Cruise Line's Jewel, is located on the 7th floor near the stern of the ship, with promenade decks on both sides, a bar at the front end, and an exhibition space at the rear end (Figure 16).

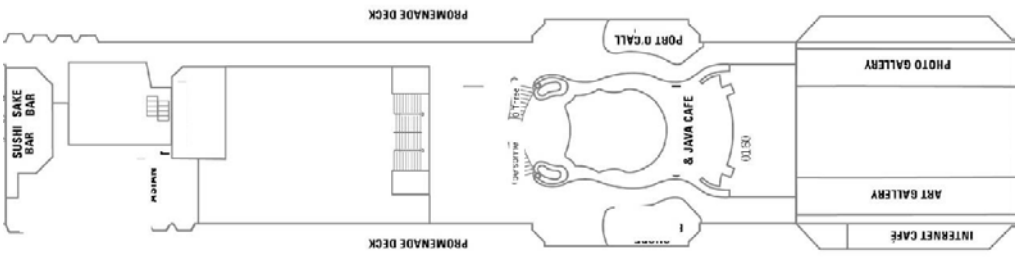
Figure 16. *Functional Layout of Atrium Adjacent Areas of the Norwegian Cruise's Jewel*



Source: https://oceanworldtravel.com/cruise-ship/.

The cruise ship without promenade decks on both sides is exemplified by the atrium of the MSC Meraviglia, where the atrium is situated on the 6th floor of the ship. This type does not feature promenade decks on either side of the atrium, with a theater at the front end and a bar and shopping area at the rear end (Figure 17).

Figure 17. *Functional Layout of Atrium Adjacent Areas of the MSC Meraviglia*

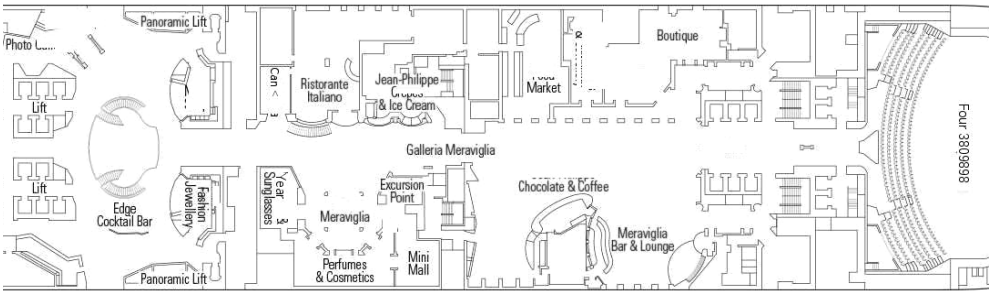


Source: https://oceanworldtravel.com/cruise-ship/.

Research on Functional Layout Form of Cruise Ship Atriums

The functional layout of typical cruise ship atriums can be divided into two types: axis sequence type and flexible layout type. The axis sequence type refers to the empty courtyards and their adjacent functional areas are distributed in a certain spatial sequence, and the layout form is basically axis symmetric. The typical atrium case is the Carnival Vista's atrium; the space sequence of the flexible layout refers to the space court and its adjacent functional areas is relatively free and flexible, and the typical atrium case is the atrium of the Norwegian Cruise's Joy (Figure 18).

Figure 18. *The Functional Layout of the Atrium of the Carnival Vista (left) and the Norwegian Cruise's Joy (right)*



Source: Author

Discussion

According to the spatial form characteristics analysis, the principles of integrated space design in cruise ship atriums are primarily applied in the conceptual and detailed schematic stages of the atrium's integrated design. By controlling specific elements of this design process, each component contributes to detailed interior design references and rules for the atrium, with the goal of providing theoretical references and technical guidance for the independent design of domestically built ships.

Six Overall Principles for Thematic Design and Interior Decor in Public Spaces aboard Cruise Ships

The overarching principles for integrated space design within a cruise ship atrium reflect considerations of safety, reasonableness, applicability, artistic quality, coordination, and technical economy (Massey 2020, Pile 2005).

Safety

Safety is an indispensable factor in the design of cruise ship atrium spaces. Pertinent safety issues in integrated atrium design encompass fire prevention, fall prevention, emergency evacuation, along with other factors related to the ship's performance, such as stability, buoyancy, and equipment usage.

Reasonableness

Reasonableness is fundamental to the design and construction of a cruise ship's atrium. It encompasses structurally sound designs, functional layout, appropriate spatial arrangement, suitable material use, and adherence to manufacturing standards.

Applicability

Applicability refers to satisfying the diverse needs of passengers from various nations, ethnicities, age groups, and educational backgrounds in the design and arrangement of atrium spaces, thereby maximizing the utility of the atrium as a communal and transitional space (Li and Wang 2013).

Artistry

Artistry lies at the core of aesthetic design and its ultimate goal. Within the framework of cruise ship aesthetics and guided by architectural aesthetics, the atrium space is designed in terms of spatial form, decorative style, and functional layout, aiming to create a vivid, unique public space that helps to craft a distinct brand identity and showcases its themes and operational characteristics (Deng and Deng 2010).

Coordination

The cruise ship atrium serves as an integration of functional, structural, and stylistic elements in a public space and acts as a hub of traffic and communal interaction. Coordination is thus a necessity in the arrangement of integrated atrium spaces. This includes harmonization with other spaces such as cabins, public corridors, other public activity spaces, and internal management spaces, as well as within the various functional areas and decorative elements of the atrium itself (Wu and Du 2018).

Technical Economy

The structure, function, and decorative design of an integrated atrium space are influenced by the level of craftsmanship and technical conditions. With the continual emergence and development of new materials and techniques, superior

and more flexible designs can be achieved through the application of novel visual elements, thereby enhancing the distinctiveness of different cruise ship brands.

Four Strategies for the Composition of Integrated Spaces in Cruise Ship Atriums

The design of integrated spaces within a cruise ship's atrium extends beyond individual areas such as the main service desk, bar, and landmark nodes, placing considerable emphasis on the combination and sequential arrangement of different functional spaces. Broadly speaking, the compositional principles of integrated space design in a cruise ship's atrium encompass clear spatial circulation, seamless spatial transitions, thematic harmony, and emphatic layering of focal points.

Clear Spatial Circulation

The spatial flow of a cruise ship's public spaces includes both planar and three-dimensional circulation, reflecting specific functional demands and spatial relationships. It also serves as a crucial basis for spatial composition. Organizing the sequence of various circulation activities and arranging spatial sequences play a significant role in the expression and experience of a cruise ship's public space theme.

Seamless Spatial Transition

The seamless transition of spatial sequences involves the designer strategically and flexibly organizing the beginning, continuity, transition, and culmination of public spaces on a cruise ship. The design's core principle is to emphasize the harmonious beauty in changing public spaces, promoting an organic sense of order. Every design arrangement of a spatial sequence must account for the theme, spatial form, decorative style, and functional layout of its constituent public spaces.

Unified Thematic Harmony

In the design and expression of a cruise ship's public space theme and interior decor, each element should be subordinate to the whole, maintaining unity amid variety. The atrium, corridors, and elevator spaces on a cruise ship should consider their mutual relations and interpenetration in terms of thematic orientation, spatial form, decorative style, and functional positioning. While ensuring harmony with the overall theme, individual characteristics should be highlighted and represented.

Emphasis on Hierarchical Focal Points

In the spatial combination and sequential arrangement of different public spaces on a cruise ship, one should account for the primary and secondary relationships among the various public spaces. The primary spaces should serve as the core, and the arrangement of secondary spaces should facilitate the functionality of primary spaces. Spaces with external links should be near traffic hubs, while internal use spaces should be relatively concealed. Spatial composition should ensure clear and complete contours of primary spaces, and the overall layout should emphasize balance and focus.

Conclusion

The key efforts of this study are as follows: Initially, comprehensive data collection and research were conducted on atrium spaces of representative cruise ship brands both domestically and internationally using methods such as internet big data research, literature review, and expert consultations. Subsequently, through data statistics, cluster analysis, case studies, and other methods, a detailed description and analysis of atrium spaces from the three main constituent elements - spatial form, decorative style, and functional layout - were conducted. This led to the clarification of the atrium's role as a traffic hub, its representational methods, and layout features, ultimately summarizing design principles and strategies.

Acknowledgments

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Early STEAM Education Practice: Application of Graph Theory through Teaching Assistants

By Michihiro Sakai[*]*, Hiroshi Miki*[±] *& Shunsuke Nakamura*[°]

In the age of Society 5.0, which is the concept of a future society developed by the Japanese government, science, technology, engineering, art, and mathematics (STEAM) human resources with the skills to grasp things from multiple perspectives and solve problems will be required. Furthermore, Society 5.0 indicates that the National Institute of Technology (KOSEN) will become the STEAM center for elementary and junior high school students, as part of the efforts to establish a system that supports STEAM education. Since 2019, we have practiced STEAM education as part of "Liberal Arts Special Lectures" for 4th-year students of the main course (1st year of the undergraduate course). In these lectures, the teachers of liberal arts subjects present themes using their specialties, such as mathematics, debate, and economics. Collaborative learning between students from various departments led them to deep learning, which was a fusion of knowledge and creation. However, there are few opportunities to give back to society, particularly a platform to disseminate the acquired mathematics ability. Therefore, we aim to realize early STEAM education and give back to society by creating STEAM teaching materials on graph theory in open courses for junior high school students between the ages of 13 and 15 with help from teaching assistants who studied graph theory in the liberal arts special lectures. Moreover, through a course on graph theory, the course will not only arouse students' interest in mathematics, but also provide them with clues to develop their multifaceted ideas.

Keywords: *society 5.0, graph theory, open course for junior high school students, teaching assistants, liberal arts special lecture*

Introduction

Introduced by Yakman (2008), science, technology, engineering, art, and mathematics (STEAM) education is an approach to learning that uses science, technology, engineering, the arts, and mathematics as access points to guide student inquiry, dialogue, and critical thinking to solve problems in the real world. As an attempt, we have formulated financial education material on simple interest and compound interest from the perspective of STEAM education, i.e., a fusion of economics and mathematics. Moreover, we have used this material in an open

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course for citizens by utilizing the abilities of liberal arts special course students and the 3rd-year students who studied both subjects as instructors. As a result, we have been highly rated by the participants and the students have had a good opportunity to give back their acquired knowledge and ability to society.

As another attempt, this work mainly aims to create STEAM teaching materials on graph theory for open courses for junior high school students and practice early STEAM education; liberal arts special course students are employed as teaching assistants, and the acquired mathematics ability is returned to society.

Graph theory is a mathematical theory about figures consisting of a set of vertices and edges; it has one of its origins in 1736 when Leonhard Euler solved the “Königsberg problem,” which is closely related to the single stroke. In the era of big data, it has become important not only to analyze each individual element but also to analyze how these elements are connected and what properties they have as a whole. Graph theory, which is a powerful weapon for data analysis to be handled in future mathematical learning, is now attracting a great deal of attention.

Additionally, since a graph is easily understood visually and little prior knowledge is required to grasp it, it is suitable as a STEAM learning material for a wide number of generations.

One of the objectives of mathematics in junior high school is "to deepen intuitive views and ideas about figures through activities such as observation, manipulation, and experimentation with plane and spatial figures, and to cultivate the ability to consider and express figures logically". This paper deals with the development and practice of teaching materials for mathematically considering real-world problems with discrete structures, using graphs as examples of plane figures that students are currently studying.

The open course carried out in 2022 is divided into three parts: an introduction to graph theory, including the Königsberg problem and single stroke, applications to social networks, and applications to maximum flow and minimum cut problems. The findings reveal that junior high school students provide high survey ratings, whereas teaching assistants have an invaluable opportunity to give back to society by making use of their acquired skills. The results of a questionnaire demonstrate that our course is effective for learners, and its potential as a STEAM teaching theme is shown. Moreover, the teaching assistants can study graph theory in depth because of the lectures; they can obtain new results and successfully present their research at the 28th KOSEN Symposium in 2023.

Herein, we first describe the graph theory in three parts: an introduction including the Königsberg bridge problem and one stroke one, the connections in society that can be represented by graphs, an algorithm called the Ford-Filkerson method. Second, the content of our practice is outlined, and we review the scenes of open courses with photos, including a description of the results of the questionnaire obtained from the participants. Finally, we present concluding remarks and future scope.

Graphs

In this section, we introduce the graph and its notation. First, we define graphs,

which are the theme of this open course, and define the degree, which is a quantity used to characterize graphs. Consider the diagram shown in Figure 1.

Remark. The graph we are dealing with here is a set of points and edges, which is different from a function graph.

Example 1. Points *P, Q, R, S,* and *T* are called vertices, the lines are called edges, and the entire diagram is called a graph. The degree of a vertex is the number of edges with the vertex as an endpoint. For example, the degree of vertex *P* is 3, and the degree of vertex *Q* is 4.

Figure 1. *An Example of Graphs*

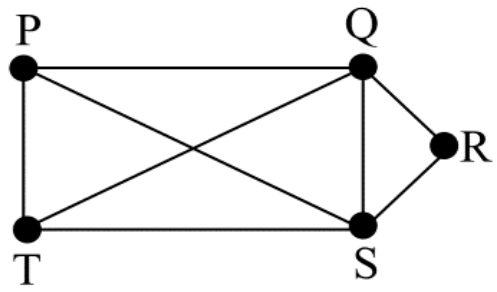


Figure 1 presents a graph. Formally, graph *G* consists of a finite non-empty set (*V*) of objects called vertices (the singular is a vertex) and a set (*E*) of 2-element subsets of *V,* called edges. Therefore, graph *G* is a pair (an ordered pair) of two sets (*V* and *E*). Thus, some write $G = (V, E)$. Hereinafter, for simplicity, a vertex is referred to as a point. The vertex set of graph *G* is denoted by $V(G)$, and the edge set of graph *G* is denoted by $E(G)$. The cardinality of $V(G)$ is the order of *G*, and the cardinality of $E(G)$ is the size of *G*. For example, the order and size of the graph shown in Figure 1 are 5 and 8, respectively.

There are many numbers, referred to as parameters, associated with graph *G*. Knowing the values of specific parameters provides us with information about *G* but rarely tells us the entire structure of *G*. We mentioned the best-known parameters: the order and the size. Further, numbers were associated with each vertex of the graph. This is called the degree of a vertex. The degree of a vertex (v) in graph *G* is the number of edges incident on v and is denoted as $\deg(v)$. For example, for vertices *P* and *Q* in the graph shown in Figure 1, $\deg(P) = 3$ and $\deg(Q) = 4$, respectively.

Next, we define connected graphs. Most graphs covered in this open course were connected graphs.

Definition 2. A graph is connected if it cannot be expressed as a union of graphs.

What we have shown in Figure 1 is a connected graph. Graph *G* is said to be connected if any two vertices (x, y) in *G*, *G* have an *x–y* path (a path in a graph is a finite sequence of edges that joins a sequence of vertices that are all distinct, and *x–y* path is a path from x to y).

Structure of the Open Course

In this class, we set graph theory as the theme for early STEAM education and provide an opportunity for students who have studied it in Advanced Liberal Arts to teach it as TAs, aiming not only to arouse students' interest in mathematics but also to give them clues to have multiple perspectives. Therefore, the class will be organized as follows.

(a) Learning contents

Graph theory and its application.

(b) Construction

- Participants

Thirty-four Junior high school students (1st to 3rd grade)

- Leaders

Three teachers and two teaching assistants (TAs) who studied graph theory in a special lecture on the liberal arts

- Time

210 (60 + 60 + 90) min

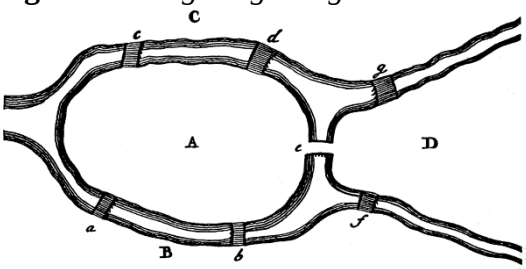
The Content of our Practice

Our practice in graph theory consists of three parts. First, as an introduction to graph theory, we introduce the definition of graphs and topics in graph theory such as the Königsberg bridge and one stroke. Next, we will look at some of the connections in society that can be represented by graphs and some of the things that become clear by doing so. Finally, as an application of graph theory, we introduce an algorithm called the Ford-Filkerson method.

(a) Introduction to graph theory

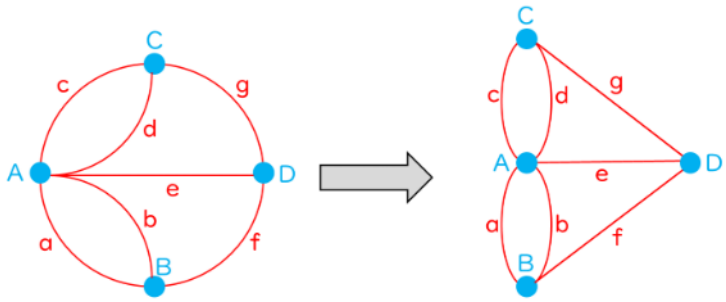
First, we showed a diagram of the Königsburg bridges and asked whether or not you could cross each of the seven bridges shown in Figure 2 once and return to your starting point.

Figure 2. *Königsberg Bridge*



Next, we explained how the basic idea of topology was used: crossing a bridge was independent of the shape and size of the river, land, and bridge. The graph was constructed by transforming (continuously) the land shown in Figure 2 as points and the bridges connecting lands as lines, as shown in Figure 3.

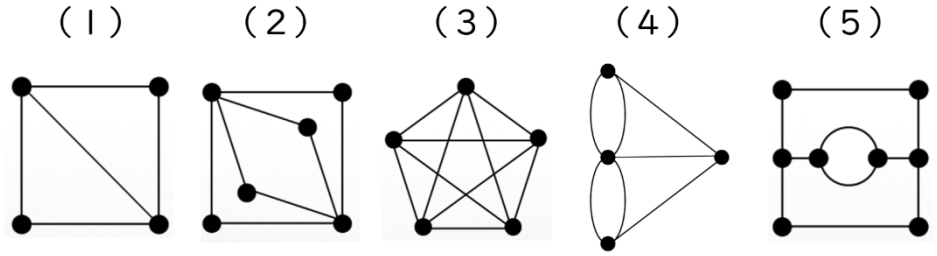
Figure 3. *Figure of a Graph*



Remark 1. This problem is equivalent to asking whether or not the graph in Figure 3 has an "Eulerian trail" (as defined below).
To familiarize the participants with one-stroke writing, the following questions were asked.

Exercise 1. Determine if the following graph can be written in one stroke.

Figure 4. Some Graphs



Further, we defined the odd vertices and gave the problem of examining the relationship between the number of odd vertices and the possibility of one stroke.

Exercise 2. A vertex with an odd degree is referred to as an odd vertex.

(1) Fill in the table below for the graph in Exercise 1.
(2) How many odd vertices would make one stroke possible?

Table 1. *The Number of Odd Vertices and Possibility of One Stroke*

	(1)	(2)	(3)	(4)	(5)
Number of odd vertices					
Possible or not					

After explaining the necessary and sufficient conditions using simple examples, the conditions for writing one stroke were provided.

Theorem 1. A connected graph is one stroke possible if and only if the number of odd points is 0 or 2.

After defining the Eulerian graphs and having the students examine whether the graph in Exercise 1 is an Eulerian graph or not, we provided the necessary conditions for it.

Definition 3. A connected graph (G) is Eulerian if there is a closed trail that includes every edge of G.

Exercise 3. Determine whether the graph in Exercise 1 is an Eulerian graph or not.
Theorem 2. A connected graph (G) is Eulerian only if the degree of each vertex of G is even.

After defining the Hamilton graphs and having the students examine whether the graph in Exercise 1 is a Hamilton graph or not, we provided the necessary conditions for it.

Definition 3. A Hamiltonian cycle is a cycle that visits each vertex precisely once. A graph that contains a Hamiltonian cycle is referred to as a Hamiltonian graph.

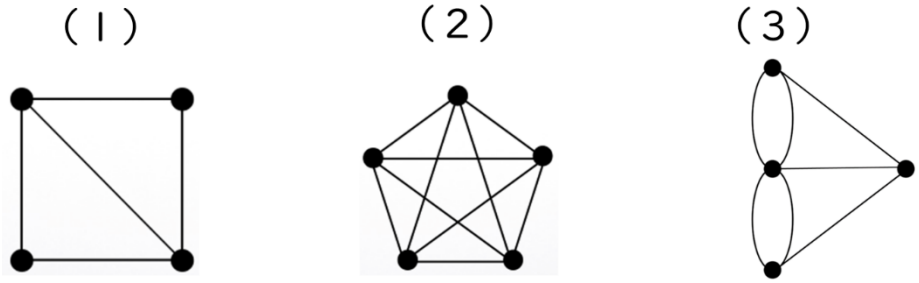
Exercise 4. Determine whether the graph in Exercise 1 is a Hamilton graph or not.

We introduced the "sufficient" condition for a graph to be a Hamiltonian graph and asked students to check that the following graph satisfies this condition.

Theorem 3 (Ore). If G is a simple graph with n ($\geqq 3$) vertices and if $\deg(v)$ and $\deg(w) \geqq n$ for each pair of nonadjacent vertices, v and w, G is a Hamiltonian.

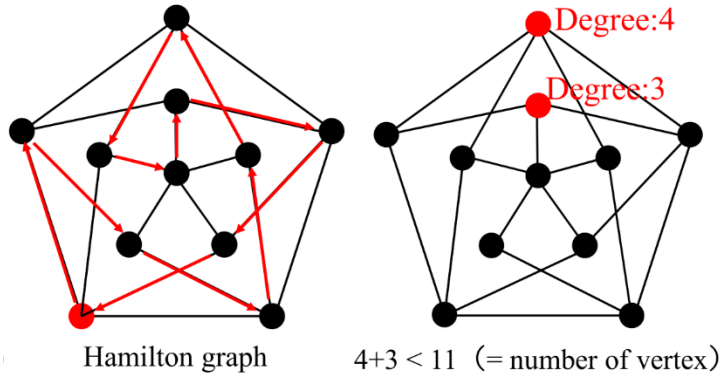
Exercise 5. Verify that the following graph satisfies Ore's condition.

Figure 5. *Some Graphs*



We provide an example of a Hamiltonian graph for which the inverse of Ore does not hold and show that the methods for discriminating Hamiltonian graphs are still being studied.

Figure 6. *Example of a Graph that is Hamiltonian but does not Satisfy the Ore's Condition*

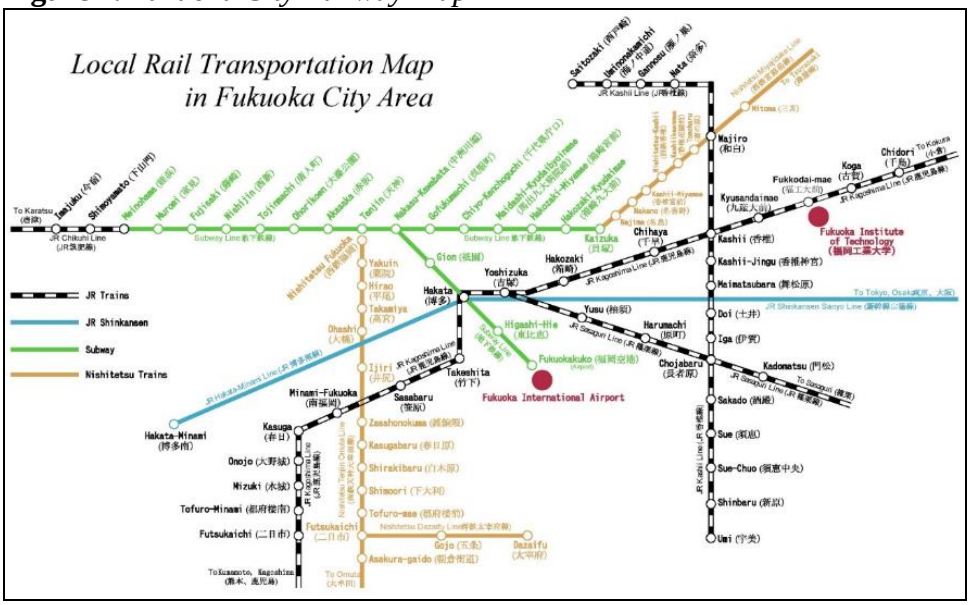


(b) Applications to social networks

The subject of this part is the centrality of a vertex in a given graph, which has been frequently used in network science since the end of the last century.

Graphs can be applied to effectively describe the structure of many social situations. In these cases, the word "network" is used more often than a graph. (Thus, in this part, "network" and "graph" are almost equivalent. However, in the next part, "network" is used in a more restricted sense.) For example, Figure 7 shows the railway network map in the Fukuoka city area.

Figure 7. *Fukuoka City Railway Map*



Source: https://ontheworldmap.com/japan/city/fukuoka/fukuoka-rail-map.html.

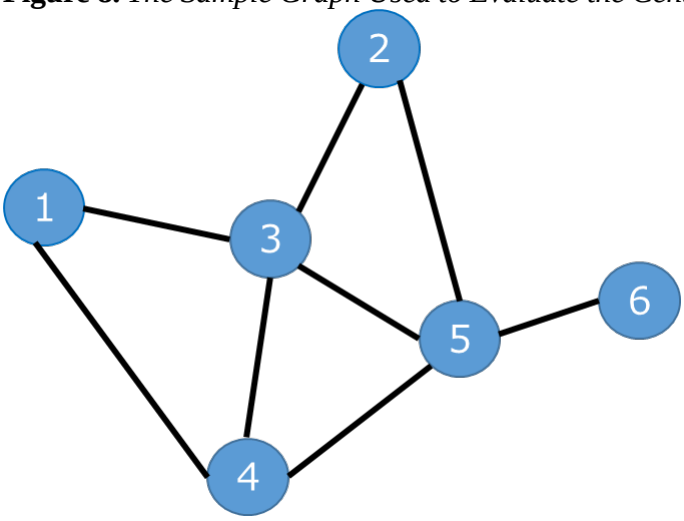
In this case, each vertex corresponds to a station and each edge corresponds to a railway path between two stations. We emphasized that we focused only on whether one station is (directly) connected to another station by a railway or not. The distance between the two stations does not matter, although, in reality, the distance or time it takes to move between them are sometimes important factors.

The centrality indicates the importance of a vertex in the graph: the higher the centrality, the higher the importance of the vertex. The meaning of "important" depends on the purpose and context. Thus, many different definitions of centrality have been proposed, and choosing, or sometimes developing, a centrality suitable for a specific purpose is a substantial problem.

We examined three types of centrality in this lecture: degree, closeness, and betweenness centralities. These are easily evaluated, and the ideas on which they are based are easy to understand.

We began by introducing two quantities required to define the centralities: the degree of a vertex and the distance between the two vertices. For simplicity, we assumed that each edge was undirected and unweighted. As an example, consider the graph shown in Figure 8.

Figure 8. *The Sample Graph Used to Evaluate the Centralities in the Lecture*



As explained in the second section, the degree of a vertex is the number of edges connected to it. For example, the degree of vertex 1 is 2 because two edges are connected to it. The degree counts the number of vertices directly connected to the vertex. Subsequently, we consider a path from one vertex to another along the edges of the graph. The distance is the least number of edges necessary to start from one vertex and move to another; such a path is called the shortest path. For example, the distance between vertices 1 and 5 is 2, since the shortest paths are 1→3→5 and 2→4→5, and each of them consists of two edges.

The degree centrality is defined as the degree of a vertex. This can be easily evaluated and understood. Typical social examples include large stations with many connected railway lines and influencers on social networking services with

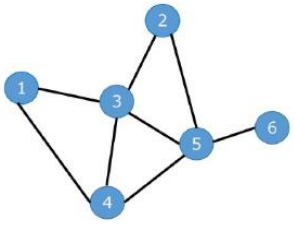
many followers. A vertex with a high degree centrality is important in the graph because it can directly affect many other vertices.

Briefly, a vertex with high closeness centrality is close to any other vertex. The closeness centrality is defined as the reciprocal of the average distance between a vertex and all other vertices in the graph. For example, we evaluated the closeness centrality of vertex 1 in the graph shown in Figure 8. The distances from vertex 1 to vertices 2, 3, 4, 5, and 6 were 2, 1, 1, 2, and 3, respectively. Thus, the average distance was 9/5, and the closeness centrality was 5/9 ≒ 0.556. The closeness centrality is useful in transportation, communication, etc.

The betweenness centrality measures the extent to which a vertex is involved in the (indirect) connection with other vertices in the graph. In other words, if a vertex with high betweenness centrality is removed, many pairs of connections will be cut off or become relatively long. For example, it is utilized in traffic and information exchanges. It is defined as the proportion of the shortest paths between two vertices that include the vertex. For example, we evaluate the betweenness centrality of vertex 3 in the graph shown in Figure 2. The number of pairs of vertices, excluding vertex 3, is 10. The shortest path between vertices 1 and 2 includes vertex 3; however, the shortest paths between vertices 1 and 4, 2 and 5, 2 and 6, 4 and 5, 4 and 6, and 5 and 6 do not include vertex 3. For pairs 1 and 5, 1 and 6, and 2 and 4, there are two shortest paths between them, and in each pair, one includes vertex 3. Thus, each pair is considered to contribute half. Therefore, the betweenness centrality was (1 + 1/2 + 1/2 + 1/2)/10 = 0.25.

The participants tried to evaluate these three types of centralities of all the vertices of the graph shown in Figure 8 with the help of KOSEN students. It seems that it took many participants some time to find the shortest paths of a given pair of vertices, which are necessary for the evaluation of the closeness and betweenness centralities. The results are shown in Figure 9.

Figure 9. *The Three Centralities of all the Vertices of the Graph Shown Leftward (the Same Graph as Shown in Figure 8) the Maximum Values in Each Centrality are Colored Red*

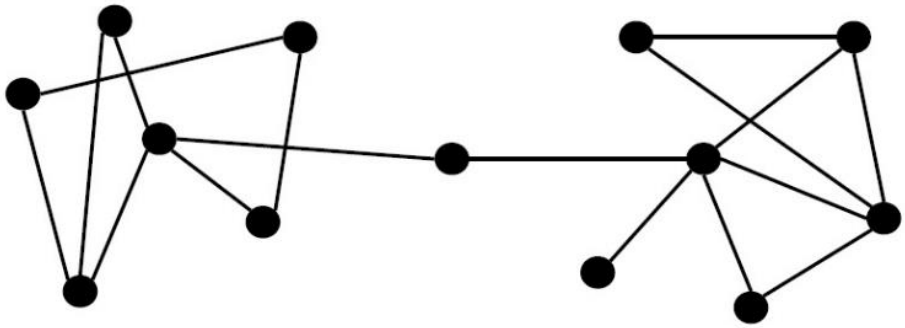


vertex	Degree Centrality	Closeness Centrality	Betweenness centrality
1	2	0.556	0
2	2	0.625	0
3	4	0.833	0.25
4	3	0.714	0.1
5	4	0.833	0.45
6	1	0.5	0

In this example, no matter which type of centrality we considered, vertices with a high centrality almost coincide. This is because the size and order of the graph (i.e., the numbers of vertices and edges) is small and the shape of the graph is “typical” for the social network. We commented that for a graph with an extreme shape, which is a vertex with high centrality depends on the type of centrality (see

Figure 10). This is sometimes the case. Finally, we commented that as the size of the graph increases, it will be a terrible task to evaluate the centralities by hand; therefore, we use a computer to analyze a real social network.

Figure 10. *An Example of a Graph with an Extreme Shape. The Vertex at the Center Bridges the Left and Right Clusters. The Degree Centrality of the Center Vertex is not Considerably High; however, the Closeness and Betweenness Centralities are High*



(c) Applications of the graph theory: Maximum flow problems and Ford–Fulkerson algorithm

In this lecture, participants analyzed transportation capacity using algorithms related to graph theory to understand the practical applications of graph theory. We constructed the contents of the lecture as follows:

- Maximum flow problem and networks
- Flow networks
- Max-flow min-cut theorem
- Residual networks
- Ford–Fulkerson algorithm
- Exercises

The following are the descriptions of each content.

Maximum Flow Problem and Networks

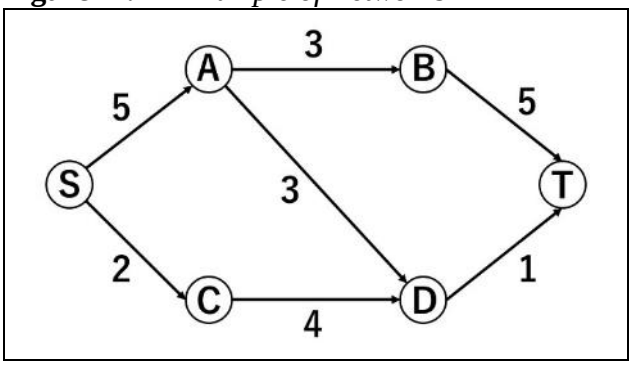
The maximum flow problem is the problem of determining the maximum amount that can be transported from the starting point to the terminal point on a graph.

For example, the problem of determining the maximum amount of goods that can be transported from point S to point T in the graph shown in Figure 11 is called the maximum flow problem.

The edges of the graph shown in Figure 11 indicate the direction in which the goods can be transported. Additionally, the maximum quantity of goods that can be transported is indicated at the edge. As shown in Figure 11, a graph with starting

and terminal points and with a defined direction and non-negative integer values on the edges is called a network.

Figure 11. *An Example of Networks*



Flow Networks

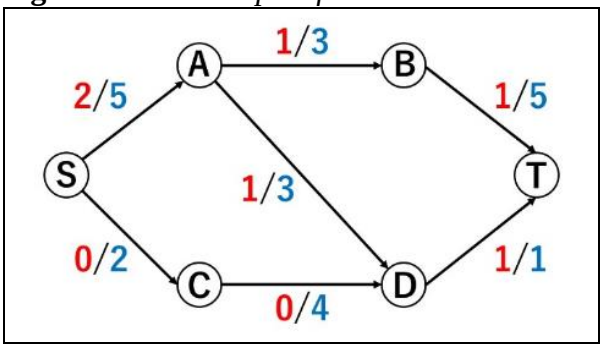
A correspondence that assigns a nonnegative integer to each edge of the network under the following constraints is called a flow.

- **Capacity constraints:** The non-negative integer assigned to each edge is less than or equal to the maximum amount that can be transported.
- **Balance constraints:** The inflows and outflows at each point are the same, except for the starting and terminal points.

In other words, flow is a method of transporting everything from the starting point to the terminal point, maintaining the upper limit of the amount that can be transported at each edge.

The graph shown in Figure 12, which is called a flow network, is based on the network shown in Figure 11, with capacity constraints represented by blue numbers and flows represented by red numbers. The flow network shown in Figure 12 shows how to transport two goods from point S to point T.

Figure 12. *An Example of Flows*



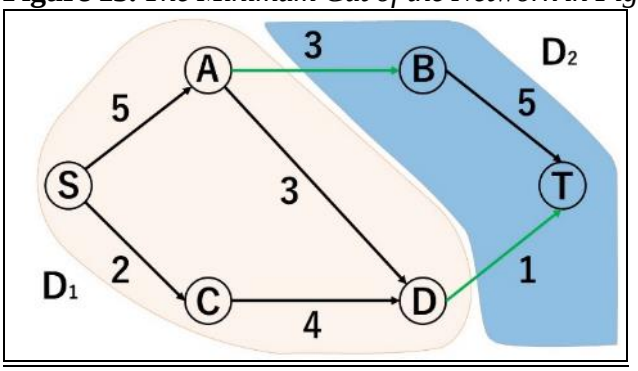
Max-flow Min-cut Theorem

The division of all points into two regions, D1 containing the starting point and D2 containing the terminal point, is called a cut. The sum of the capacities of the edges flowing from region D1 to region D2 is referred to as the capacity of the cut. The cut with the smallest capacity is referred to as the minimum cut.

Figure 13 shows an example of a cut in the network shown in Figure 11. The capacity of the cut is 3 + 1 = 4, which is the minimum cut.

The max-flow min-cut theorem states that the maximum quantity that can be transported from the starting point to the terminal point is equal to the capacity of the minimum cut. For example, in the network shown in Figure 11, the maximum amount that can be transported from the starting point to the terminal point has a minimum cut capacity of 4. This indicates that the number of goods that can be transported is higher than the flow, as shown in Figure 12.

Figure 13. *The Minimum Cut of the Network in Figure 11*



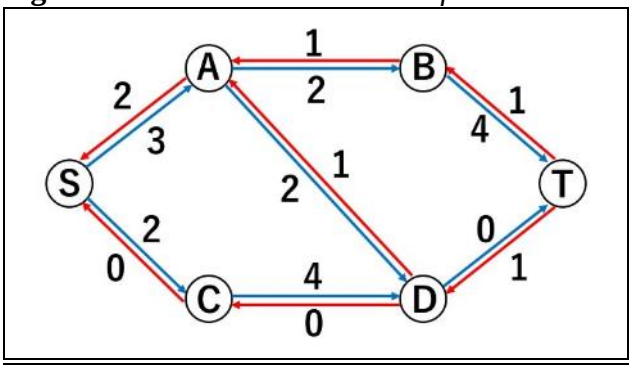
Residual Networks

The residual network is a graph representing how much more flow can be added and how much more flow can be returned. For example, Figure 14 shows the residual network created based on the network shown in Figure 12.

The flow from point A to point B is 1, whereas the maximum amount that can be transported is 3. Therefore, it is possible to flow an additional 2 from point A to point B. Since the flow is 1 from point A to point B, it is possible to return 1 from point B to point A. Notably, if 1 is returned from point B to point A in the residual network, the flow from point A to point B becomes 0 in the flow network.

Similarly, by representing how much flow can be added and how much flow can be returned, a residual network can be created, as shown in Figure 14.

Figure 14. *The Residual Network of the Network in Figure 12*



Ford–Fulkerson Algorithm

The following algorithm can be used to find the maximum amount that can be transported and the transport method. This is known as the Ford–Fulkerson algorithm.

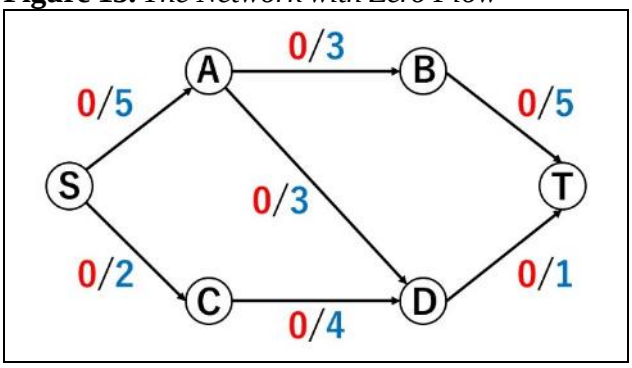
− Algorithm (Ford–Fulkerson algorithm)

Step 0: The initial flow is set to 0.
Step 1: Create the residual network from the flow network.
Step 2: Find a path in the residual network from the starting point to the terminal point, consisting of edges assigned to positive integers. If there is no such path, stop the process.
Step 3: Update the flow in the flow network corresponding to the path found in Step 2 and return to Step 1.

− Ford–Fulkerson example

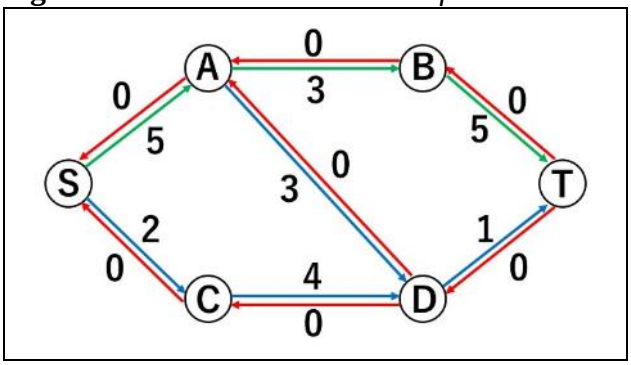
The first flow is set to zero.

Figure 15. *The Network with Zero Flow*



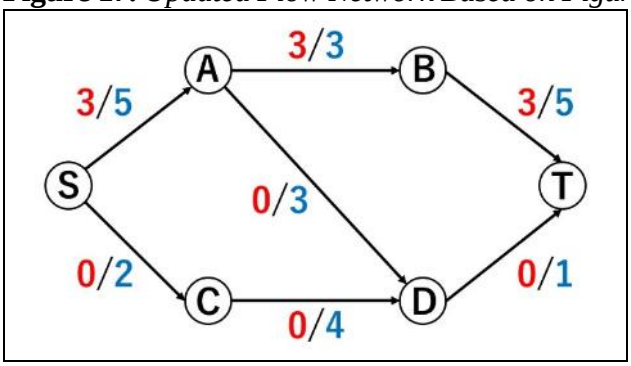
Subsequently, a residual network is created. From this, we find a path consisting of edges to which a positive integer is assigned. Here, we select path S→A→B→T.

Figure 16. *The Residual Network of the Network in Figure 15*



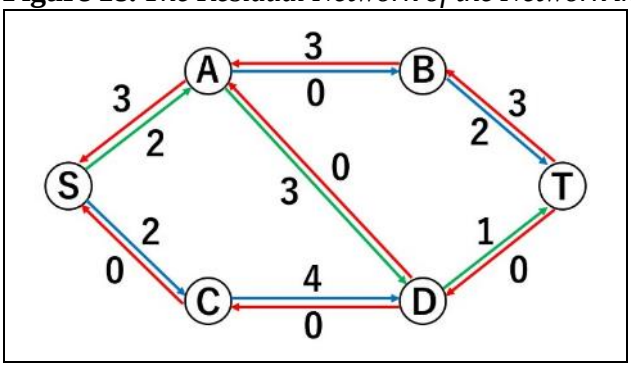
The minimum capacity among the three edges is 3 (A→B). Accordingly, the flow network is updated.

Figure 17. *Updated Flow Network Based on Figure 16*



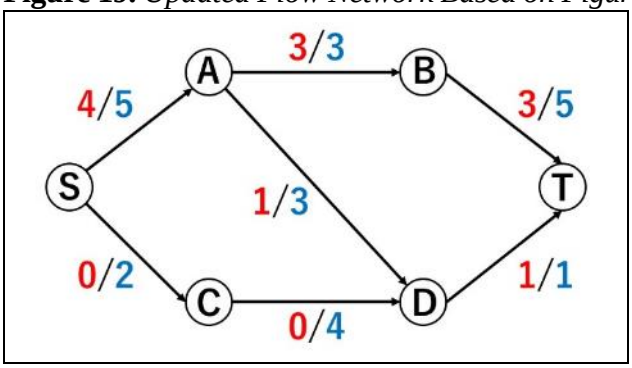
Afterward, we create the residual network again and select another path: S→A→ D→T.

Figure 18. *The Residual Network of the Network in Figure 17*



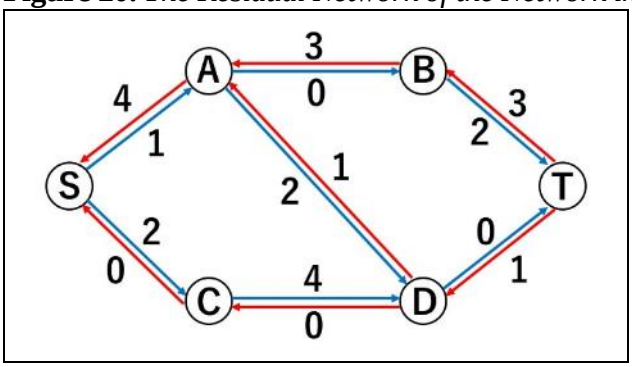
The minimum capacity of the three edges is 1 (D→T). Accordingly, the flow network is updated (this is the maximum flow according to the max-flow min-cut theorem).

Figure 19. *Updated Flow Network Based on Figure 18*



We create a residual network; however, there is no path from the starting point to the terminal point consisting of edges that are assigned positive integers. Thus, the procedure is discontinued.

Figure 20. *The Residual Network of the Network in Figure 19*

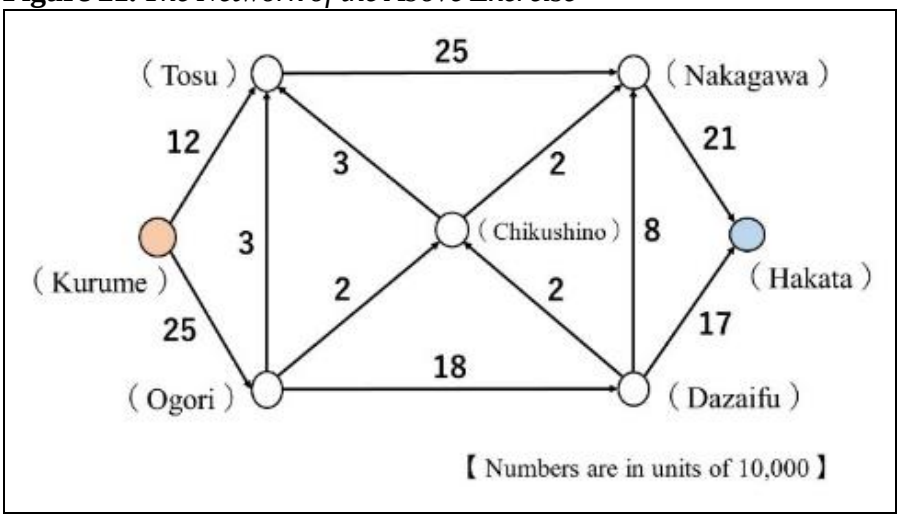


Exercises

At the end of the lecture, participants analyzed their transportation capacity during the following exercise.

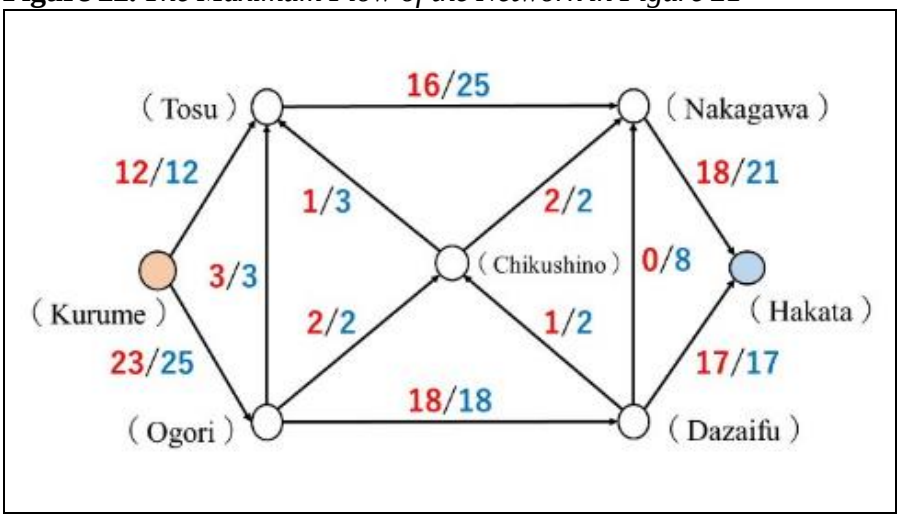
- **Exercise:** Kurume is crowded with people returning to Hakata after the Chikugo River Fireworks Festival. How many people should be transported between each route to deliver as many people as possible to Hakata? Note that the arrows indicate passable routes, and the numbers indicate the number of people that can be transported.

Figure 21. *The Network of the Above Exercise*



− **Sample answer:** It can transport up to 350,000 people, which can be achieved by transporting as shown in the figure below.

Figure 22. *The Maximum Flow of the Network in Figure 21*



The participants completed this exercise using the Ford–Fulkerson algorithm. They attempted this exercise with advice from teaching assistants, and almost all participants could arrive at the correct answer. We believe that the participants could understand that graph theory could be used in familiar situations by completing this exercise.

Some Scenes from the Open Course

In this section, we review the scenes of an open course using photos. A teacher and student showed slides on the screen, and the participants solved the exercise (see Figure 23).

Figure 23. *The Scene of Open Course*

Discussion of Practice Results

To verify the achievement of the project's objectives of "providing opportunities for our students who have studied graph theory to teach what they have learned (as TAs)" and "providing participants with opportunities to arouse their interest in mathematics and to gain multiple perspectives," we interviewed TAs and a conducted a survey of participants after the course was over. The results of the interviews for the TAs are as follows.

- "I was nervous, but it was a good experience."
- "I was glad to have the opportunity to teach".
- "It was difficult to teach what I had studied to others, but it was a good experience."
- "Preparing for the class was difficult, but teaching it helped me understand it even better".
- "I would like to use this experience to teach others in the future."

According to interviews, the TAs not only had the opportunity to teach what they had learned, but also experienced the challenges and joys of teaching.

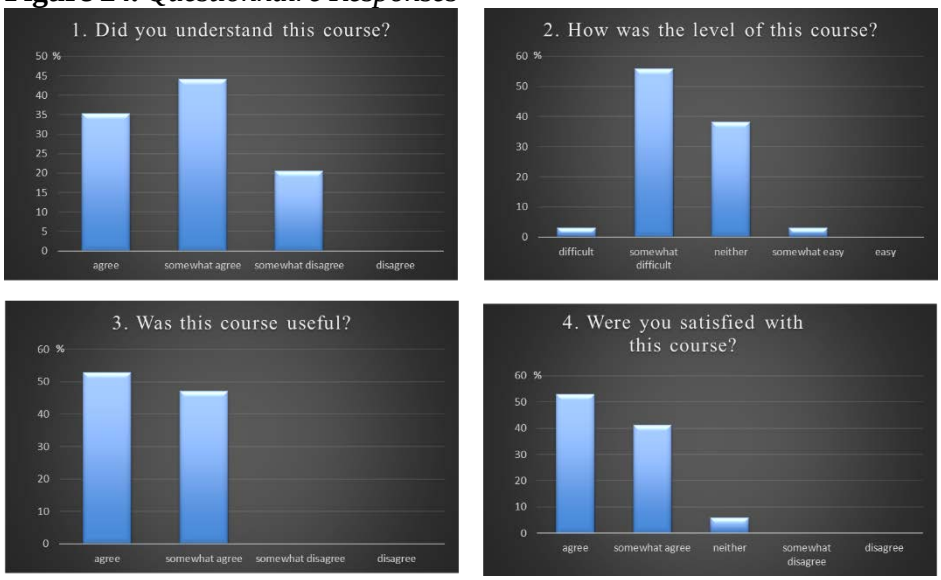
The items and the order of them in the survey to the participants are as follows, where items 1 and 3 are "agree," "somewhat agree," "somewhat disagree," and "disagree;" item 2 is "difficult," "somewhat difficult," "neither," "somewhat easy," and "easy;" and item 4 is "agree," "somewhat agree," "neither," "somewhat disagree," and "disagree".

Item 1: Did you understand this course?
Item 2: What was the level of this course?

Item 3: Was this course useful?
Item 4: Were you satisfied with this course?

The results of the responses to the questionnaire items are shown in the figures below, with the numbers representing the response rate for each option.

Figure 24. *Questionnaire Responses*



The total percentages of "agree" and "somewhat agree" were more than 80% for all the questions except for 2. On the other hand, we found that more than 60% of participants found the classes difficult or somewhat difficult. We included an open-ended section in our questionnaire. Some of the comments are as follows.

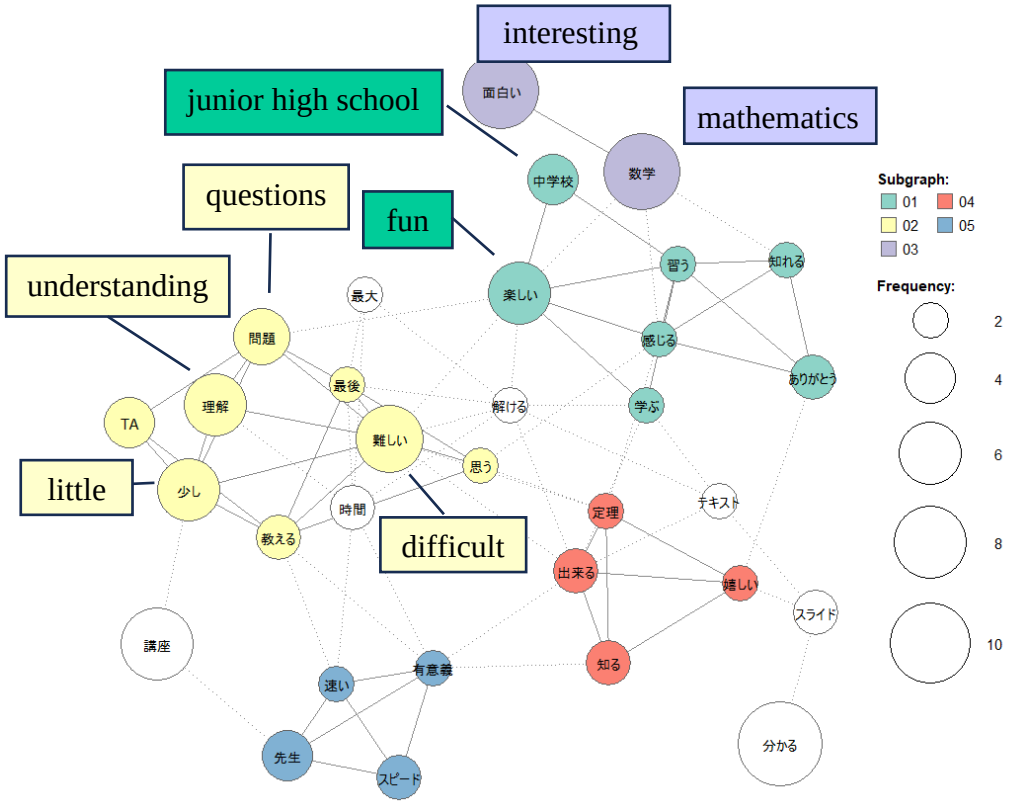
- Because it was the content I had not learned in junior high school, the class was interesting and I enjoyed solving the problems.
- I was glad that the course was useful in the future and that practice problems were provided. The applications were a little difficult, but I could roughly understand them. It was good to learn about theories and theorems that I didn't know.
- It was a little difficult, but thanks to the TAs teaching me, I understood a little.
- I enjoyed learning many things that I did not learn in junior high school.

I felt again that mathematics is interesting.

- It was good to feel the fun of mathematics. I thought the theorems of mathematicians such as Euler were very difficult, but they were surprisingly easy to understand.
- It was a good experience for me to experience the mathematics I learn in high school. It was difficult, but it was fun when I could solve it.
- It was very meaningful to learn how math and science knowledge are used in society.

Moreover, we used KH Coder which was a software for text mining to analyze the comments in detail. In KH Coder, the size of the circle represents the frequency of occurrence of a word, the line represents words that appear simultaneously, and the color represents groups of related words. The comments were written in Japanese, and to avoid the influence of language structure we performed a KH Coder analysis in Japanese. The output results are as follows.

Figure 25. *Co-occurrence Network of Comments by KH Coder*



Subgroup 01 can be assumed to represent “I enjoy learning new knowledge,” 02 “The exercises were difficult, but I could understand them with the support of the TA,” 03 “Mathematics is interesting,” 04 “I am glad to know new theorems,” and 05 “The teacher’s class is fast paced but meaningful”.

The comments and their analysis indicate that the course has achieved some degree of success in arousing interest in mathematics. Moreover, the last comment may suggest that the survey provided an opportunity to have a multifaceted viewpoint. In addition, we observed the activities of TAs and participants in class. During the exercise-solving time, we saw participants eagerly solving exercises and TAs actively approaching them and answering their questions.

Conclusion of this Effort and a Future Subject

Our goal is to "provide our students with the opportunity to teach what they have learned about graph theory", and to "spark participants' interest in mathematics and give them the opportunity to gain multiple perspectives" through this course.

Interviews with TAs, survey responses, KH coder analysis of the comments, and observations indicate that the course is somewhat effective for learners and has potential as a STEAM resource. On the other hand, we found that participants did not fully understand the relevance of mathematics to other fields or acquire multiple perspectives. Moreover, since the participants were interested in mathematics to begin with, the survey was not sufficient to determine changes in their attitudes about it.

In the future, we would like to create STEAM teaching materials that emphasize the relationship between mathematics and other fields, and conduct surveys before and after the class to investigate changes in participants' awareness and verify the effectiveness of our efforts.

We now describe STEAM teaching materials for future use. "*Knot theory*" is easy for beginners to understand because it is not necessary to know its background well, and there are various teaching materials from which they can learn visually. The knot theory is associated with various fields, such as quantum field theory in physics, molecular design in chemistry, and DNA in biology. In the future, we intend to create STEAM teaching materials related to physics and chemistry.

The next material is the "*L-S category*" (Cornea et al. 2003, Sakai and Miyaji 2013), which is an invariant for various figures. We find it easy to begin because we can learn it visually as a knot theory and because we need little preliminary knowledge of it. For these reasons, this theme would be interesting to students. For example, the L–S categories of a torus and a Klein bottle are both two. There is a *fibrewise* version of the L–S category, which is known to have a possibly different value from the ordinary L–S category. As a simple example, a torus has a value of two as its ordinary L–S category but one as its fibrewise version (Cornea et al. 2003). Using the property of the fibrewise A_∞-structure, one of the authors states that the fibrewise L–S category of the Klein bottle has a value of two (Sakai 2010). Additionally, it is known that the fibrewise L–S category is related to "topological complexity," a field of research involved in the motion planning of robot arms (Iwase and Sakai 2010).

Acknowledgments

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A Review of the Interrelationships between Painting, Photography, Facial Recognition, and Artificial Intelligence Technologies in Portraiture Aesthetics

By Yoong Wah Alex Wong[*] & Ernesto Carlos Pujazon Patron[±]

We see faces every day, and all of them leave us with different impressions. Our brains also respond emotionally to new and familiar faces we find in non-animated objects, paintings, and sculptures. To retain such memory of a face or express our feelings, we create portraits. Portraits have fascinated us for millennia. This paper reviews the interrelationships between painting, photography, facial recognition, and artificial intelligence technologies in portraiture aesthetics. The importance of portraits as a subject in artistic creation, studies, and research has led to various advancements in technological innovations. The inevitable role that portraits play in different mediums of art, history of art, communication, and security marks the intersection between humanity and identity, art and technology, as well as its undeniable position within the genre of art. Today the rapid development of digital tools, mobile software, and artificial intelligence allows not only the artist and designer to create portraitures but is also widely used by the public in all walks of life to create portraitures instantly. Driven by the marriage and momentum of art and technology in the field of new media art, will artificial intelligence and modern facial recognition technology take over the role of artists?

Keywords: *portrait, painting, photography, facial recognition technology, artificial intelligence*

Introduction

Ancient portraiture could be classified as either private or public art, and it depicts a specific social status within society. Portraiture was primarily considered a public art form in ancient Mediterranean civilizations such as Greece and, later, Roman and Byzantium art. According to Georges Perrot, Charles Chipiez, and Walter Armstrong, the ancient art of Egypt may be set aside in "A History of Art in Ancient Egypt" published in Paris in 1882. "Painting by no means became segregated and efficient art in Egypt; it was frequently used to attain sculpturesque quality and it never liberated itself from this subjection" (Collier 1905, p. 1). Painting can be used as a form of cremation art for the Kings, Czars, Popes, and Gods. Portraits were completed similarly to sculptures, either in bronze or marble; or as panel paintings or murals known as "Frescoes." "Portraiture" is a medium of expression of making "portraits." It continues to be one of the most intriguing genres within the art discipline (Merriam-Webster, n. d). Portraits were commonly

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used by the ancient Greeks and Romans to document the identity and personality, social background, or group affiliation of a prominent member of society (Freeland 2007, p. 97). It encompasses riveting, puzzling and even contradictory aims as portraiture could portray different means in culture, gender, psychology, condition and emotion, political and social status. Surely, it is so much more than just portraying pretty faces. Portrait painting can indeed be dated back more than five thousand years ago to ancient Mesopotamia and Egypt when it was first combined with relief sculpture in metal, clay, or stone.

The TATE Modern Museum defined the term "portrait" as a "simple representation of the physical appearance of a person" (Carmel 2022). There is a range of representations such as sculpture, sketches, photos, drawings, and paintings, where the aim is to depict likeness expression or the particular mood of a person. Some others may refer to a "portrait" as the representation of the state of mind of the person and their external physical features together. Artists' portraits have been painted over the centuries as a way of documenting a person's resemblance or sometimes a "portrait" would be expressed at his best and is often idealistic. Even when an ugly person was faithfully portrayed there would be a certain suave play of line which would go far to redeem this ugliness (Collier, 1905, 3). As stated in the Oxford English Dictionary, a portrait is interpreted as "a depiction or a person's distinction, primarily through the face, made from real life, by painting, photography, drawing, etching, or other means." (Maes 2015) This notion or definition may bring some challenges to this discourse since a CCTV record of a person's likeness (face) or physical appearance may not result in a "portrait" per se. Shearer West's book "Portraiture," for example, ascertained how almost all portraits in the West portray an aspect of the body and face as "the essence of the character, or virtues of the sitter on the other." (West 2004, p. 21). Not only is the representation of generic bodies in anatomical drawings or the drafting of idealistic figures in numerous anonymous unclothed statues a distinguishing feature of a "portrait," but so are forms of allegorical, pastoral, and symbolistic painting (Maes 2015).

When studying the history of art, particularly painting, there is a wide range of notable portraits painted by influential artists from various periods, such as *The Arnolfini Portrait* (1434) by Jan van Eyck, *The Mona Lisa* (1503-1506) by Leonardo da Vinci, *Vertumne ou Rodolphe II* (1590) by Giuseppe Arcimboldo, *Bacchus* (1596) by Caravaggio, *Rembrandt Self-Portrait* (1659) by Rembrandt van Rijn, *Girl with a Pearl Earring* (1665) by Johannes Vermeer, *V.V Gogh Self-Portrait* (1887) by Vincent van Gogh, *Adele Bloch-Bauer I* (1907) by Gustav Klimt, *American Gothic* (1930) by Grant Wood, *Self-Portrait with Thorn Necklace and Hummingbird* (1940) by Frida Kahlo, *Marilyn Monroe Diptych* (1962) by Andy Warhol, to *Self-Portrait* (1971) by Francis Bacon. The list is unmeasurable. However, each portrait has told us the way artists view their subjects. The requirement for recognizability need not imply that the portrait always be implemented in a hyper-realistic manner. This brings different "isms" such as classical, romanticism, impressionism, post-impressionism, expressionism, etc., by which artists have manifested their creativity in revealing portraits.

Background

Types of Portraits

Given the great variety of artistic poses a human being can take on and the psychological wealth which characterizes every possible personality, the artist will try to assess the best possible "pose-attitude" for the model to assume. This brings some challenges to an artist to display the best likeness (Civardi 2002, p. 6). In addition, all individuals have their characteristic posture and typical movement, which are intrinsic and part of their "being," besides there are essential physical behaviours along the "model" social convention, which allow the artist to place the subject (model) in the possession of status they belong to or aim for. An artist can create various types of portraits. For example, a "formal" portrait is where the subject (live model) poses in classical posture, paying a lot of attention to composition, the surrounding of the subject, and the symbolic representation of the subject (live model). Perhaps focusing on the aesthetic value of the subject represents time. On the other hand, an "informal" portrait is one the subject (live model) poses spontaneously by capturing the figure in motion. The category may also belong to the "expressive" portrait, where the subject (live model) can be drawn or painted with facial expression or in motion (Civardi 2002, p. 6).

It is a known and primal urgency for humans to leave a record of their existence, which is implied from the pre-historic cave painting produced across the world, from Spain to Indonesia, dating back at least 30,000 years ago (Reynolds et al. 2016, p. 9). Portrait or self-portrait records the presence of the artist together with his/her "self" subject (model); whether this served as the primary motivation or was a coincidental by-product. Modern eyes find a lot of appeal in portraits and self-portraits because of this sensation of being in the artist's presence. All portraits serve as records of identity, but the degree to which they can reveal a subject's inner self - their personality, aspirations, etc. - is frequently what sets an exceptional portrait apart from one that merely mimics external appearance. In contrast, unless it is being created as a commission for a patron with specific requirements, one person typically assumes the roles of creator, sitter, and patron when creating a self-portrait, making all the decisions regarding the appearance of the finished work of art. Some artists portrayed themselves many times throughout their lives, while others never did (Reynolds et al. 2016, p. 10). A positive example would be Albrecht Dürer (1471-1528), whose self-representations occurred throughout his life (Borchert 2021, Koerner 1996). Norbert Schneider claims in his book "The Art of the Portrait" that portraiture "developed its own identity" between the end of the Middle Ages and the 17th century. People from all backgrounds and social classes began to sit for portraits instead of merely royals, clerics, and noble art patrons (Freeland 2007, p. 97). On the other hand, the development of portraiture as a distinct genre was influenced by both humanism, which served as the Renaissance's epicentre, and the Christian Reformation. The humanist philosophy's fundamental tenet - "Man is the measure of all things" - logically assigned the portrait a position of the utmost significance. The Renaissance artists not only shared this viewpoint, but they also enhanced the character's depiction thanks to technological advancements. The oil medium,

introduced to Venice by Antonello da Messina (1430-1479), provided art with a new sensation and strength of modelling (Poldi 2009, p. 91). Leonardo da Vinci (1452-1519) gave an example of how light and shade could enhance a painting's allusion to personality and psychology. *Sfumato* is an oil painting technique by which the brush strokes are smoothed off to a certain degree, that there is a seeming transition from tone to tone (Nagel, 1993, 11). Although it is simple to find the theoretical justification for "sfumato" in Leonardo's writings, it can also be understood as the full realization of the potential inherent in the oil painting technique as it was passed down and developed in the workshop traditions (Nagel 1993, p. 15). The term "horizon" is used to refer to the literal notion of different areas and not to any effect of atmospheric perspective alone presented by Leonardo. It refers to the limits that vision encounters in the perception of all objects. This method was created to increase the level of nuance in how sensate phenomena are perceived. As a result, it increased the degree to which the understanding of oil medium painting is dependent upon the specific context in which the painted form emerges (Nagel 1993, p. 19). In Florence's Santa Maria Novella Dominican church between the years of 1425 and 1427, Masaccio regarded as the early Italian Renaissance painter, painted the "Holy Trinity, with the Virgin and Saint John and Donors." The figure appears to be larger in a scene, usually in an altarpiece, using a fresco painting technique. This is an early Renaissance portraiture example. The viewer is typically depicted looking at what appears to be a space embedded in the wall in such paintings, giving the viewer a sense of the depth of Jesus Christ's body and surroundings.

Self-Portraiture

Until Nicolas Poussin's time, the term had yet to become adequately specialized to be restricted to human (rather than animal) subjects. Michael Podro highlights three aspects that a painting corresponds to the matter or sitter in his book "Depiction." The artist can experience investigating the figure closely, seeking the sensation of motion well within the figure, and/or learning... as well as a portrait itself could serve as a method for the sitter to articulate himself with the artist's assistance (Freeland 2007, p. 97). The self-portrait has been around far longer than the term itself. The self-portrait was first used in 1831, but "autoritratto," its Italian equivalent, was first used in 1913. Before that time, accounts and historical inventories would refer to works where the artist is both the subject and the maker using phrases like "by their hand," "by himself," or "portrait of the artist." Self-portraiture developed into a distinct and well-liked genre in the Western world starting in the sixteenth century (Self-portraiture, n. d). It was not, however, an entirely new phenomenon during the Renaissance; examples can be found in early medieval manuscripts, the Classical era, and Ancient Egypt. The 17th century benefited from the standard that the portraiture of Renaissance Italy had established. Before photography sessions or personal introductions were thought to be necessary, even for a royal wedding, the painted portrait was utilized to express the physical appropriateness of the potential bride. Through the splendour of the costume and the abundance of jewellery, the court portrait also served the purpose of denoting power and rank. This characterized the "Elizabethan

Era," which describes the period in the history of England when Queen Elizabeth I was in power (1558-1603). In books, movies, plays, and television shows, this era is often romanticized as a "golden age" of English history, as described by historians.

Perhaps it was the obligation of the patron that the characteristics be rigid and ceremonially expressionless, whereas the wealth of accessories demonstrated status. In addition to a difference in "eye contact," embedded portraits may also use gesture, position or physical appearance as clues to indicate the status. Despite the rise of autonomous self-portraiture, some painters, including Durer, Rembrandt, and van Eyck, continued to include self-portraits within historical narratives over the course of the following centuries. An inspiration for a different kind of portraiture came from the Christian Reformation. In the reforming nations, religious imagery was outlawed, which increased the demand for portrait artists. Jan van Eyck's (1390-1441) "Portrait of a Man – 1433" is widely regarded as the Western world's first stand-alone self-portrait (Figure 1a below). The National Gallery in London currently exhibits the portrait, which is distinguished by the directness of the subject's gaze and the prominence of the two inscriptions, "Als ich can" and "Jan van Eyck made me on October 21, 1433." (Reynolds et al. 2016, p. 12). He added an unprecedented level of realism to the themes and characters of late medieval art and popularized the oil painting technique, which involved applying several layers of oil paint, as seen in all of van Eyck's portraits. His self-portrait painting shows the subject sitting in a three-quarters profile position and is a third the size of life. His shaven face is heavily lined with the beginnings of middle age, and his eyes are almost bloodshot. He has a piercing gaze outward and may be the first portrait in a millennium to look directly at the viewer. His prominent nose, tightly pursed wide mouth, headdress, and tired expression are all combined to create this effect. The overall expression is that of a man who, in the words of one scholar, "see things - including himself - in close-up, but without losing track of the bigger picture" (Figure 1b).

Figure 1. (a) *Portrait of a Man (Self-Portrait?), 25.5cm x 19cm, 1433* (b) *Portrait Details of Jan van Eyck.*

a)  b) 

The psychological and social interactions between the painter and the sitter that result in a portrait juncture are the main aspects that differentiate portraiture from various other forms of art. Oftentimes classical portraiture depicts a specific event or occasion, either directly or indirectly (Figure 2). This is a direct encounter between a specific individual (poser) and the artist. Charles Sanders Peirce (1839-

1914), known as the "Father of Pragmatism," was a philosopher, scholar, polymath, and scientist, who explained this distinctive quality of portraiture (Burch 2022). A symbol, according to Peirce's icon, index, and symbol semiotic theory, is an arbitrarily defined sign that is culturally associated with a specific object. An icon resembles the subject it signifies. An index places the focus according to the representation and on something else (West 2004, p. 41).

Figure 2. *Leonardo Da Vinci. "Lady with an Ermine, 1489." Oil on Canvas. 54cm x 39cm*

Proof of Presence

The ability of a portrait to evoke subjectivity can provide proof of a person's "presence." The "presence" can manifest itself in a variety of ways. For example, an image may demonstrate that the subject existed and that the artist as an ideal did not create the image. Instead, the subject was present as a model, demonstrating how the subject serves as an icon to confirm their presence. Another meaning of "presence" exists and is significant in icons. The painted subject appears to emerge from the canvas, as in Rembrandt's profound portraits. The portraits are created to portray a person's actual presence, as in attempting to bring a person into contact with us. For example, "Portrait of a Man 1632" (Figure 3a), although there is not much known about the man's identity, it indicates the skills and abilities that allowed this young artist to quickly establish himself in the biggest and the most artistically competitive town in the Dutch Republic (Schama 1999). A portrait as such (Figure 3a below) is frequently referred to as offering a special connection to the deceased. However, one could just as easily travel to distant lands or go to war with a miniature painted portrait of a loved one in their wallet or locket, as many soldiers did in earlier times (Figure 3b below). The person is replaced by the image. Again, physical resemblance is not necessary in this case. Because it functions as if an artefact expressed miraculously, a lock of an adored one's hair could substitute the image (West 2004, p. 43). The painted portrait decreased dramatically in the 20th century, while the photographic portrait noticeably

increased. Regardless of its technological origins, the artistic quality and aesthetic appeal of such types of portraits are not diminished.

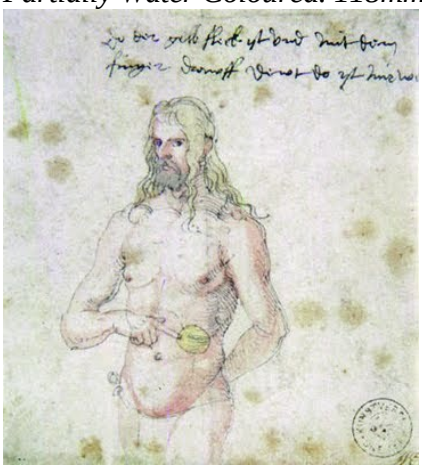
Figure 3. (a) *Rembrandt van Rijn. "Portrait of a Man, 1632." Oil on Wood. Oval: 29 ¾ x 20½ inches* (b) *Giuseppe Macpherson. "Rembrandt self-portrait," (1772-1780). Watercolour on Ivory. 6.10cm x 5.1cm*

a)  b) 

Portrait as Document

The uniqueness of portraits renders them a profound connection to historical sources; portraits are visual representations rather than records. The portrait's representation of a person, along with the specific details of the ambience, props, and attire, may provide a documentary feel. Name and age labels for the sitter can both bring up memories, and relevance of a specific moment in time. In every historical record, it is critical to balance what seems to be the presentation of "factual evidence" with the way the information was represented and understood (Figure 2). How artists express themselves and represent themselves frequently undermines any verification facts that could be added to a masterpiece, is what underpins such ambiguity concerning the documentary nature of portraiture. Portraits served as evidence in lawsuits, advocacy to find conspirators, or depicted struggles in battles during the modern period of history. Artists can use portraits for a variety of purposes. For example, in 1509-1511, Albrecht Dürer created a renowned portrait of himself to illustrate a distressing ailment to a distant doctor, which was most probably not his real appearance. He created a visual depiction of himself identifying the location of the ache in his left side around his abdomen and thoracic regions. This visual rendition was intended to convey information about his internal states of being (Figure 4).

Figure 4. *Albrecht Durer. "Self-portrait, Ill." (1509-1511). Pen and Brown Ink, Partially Water Coloured. 118mm x 108mm*



Documented portraits mainly serve as artistic, autobiography, documentaries, or affiliates, and are frequently associated with memories. Thus, with a person's death, miraculously, portrait functions as preserving the life of a deceased person or persons who have aged. A portrait can either bring the deceased to life once again or carry the deceased's personal history into the current moment, reflecting as a type of memorial or funerary oration (Pujazon et al. 2022, p. 34).

The Birth and Innovation of Technology

Portrait Photograph

The creation of the camera and photography in the 19th century left a paradox in the history of art and culture. The innovative intervention created the basis of a desiring "uniqueness" that people presumed, both astonished and dismayed by the technology. Cameras change the way people perceive, produce, and create art. Paintings no longer required being realistic because the camera captured real-time scenarios. Cameras and photography paved the way for videography, which in turn paved the way for films and movies. Art was evolving into a wide range of forms. This was merely one representation of technology permeating society. Emerging digital inventions have since transformed the field of art. Today photography pervades our lives. The various functions of photography are not only ubiquitous but also immensely essential. There are many distinct kinds and types of photographs. Some are taken for advertisements, documentary shots of sports and news events, some for criminal "wanted" posters, and some for scientific images to serve as pattern recognition in the discovery process or even as factual tools for concrete evidence and teaching (Shusterman 2012, p. 67). The implications of photography as a machine seem rather intriguing. However, it could have been a gradual evolution from the early invention of the "Camera Obscura" (Latin for a darkroom), in which people initially moved toward the identical goal of taking photographs, which has been known since Leonardo da Vinci's time (Wong et al.

2022, p. 57). The term "photography" is derived from the Greek words "phos--φως," which means "light" or "unit of illumination," and "grapho- γράφω," which means "writing." Attempting to fix the image and recreating it on a separate surface was required when taking photographs of living or non-living subjects (Forrester 2020). Such an innovation was not possible until the revelation of the light-sensitive silver compounds in the 19th century. The year 1839 is generally perceived as the year when Daguerre first publicly revealed his positive method, which was quickly followed by Talbot's declaration of the paper-based negative process (Figure 5). Centuries of development in science, quantum theory, and optical devices, along with the invention of the "camera obscura," laid the groundwork for the world's first photography. Johann Heinrich Schulze (1687-1744), a German scholar and mathematician, demonstrated in the 17th century that certain components of silver nitrate and silver chloride were charred when exposed to sunlight (Forrester 2020, Wong et al. 2022, p. 57).

Figure 5. *Daguerreotypes:* (left) *Jacques Louis Mandé Daguerre (1787-1851) by Jean-Baptiste Sabatier-Blot and* (right) *William Henry Fox Talbot (1800-1877) by Antoine Claudet, Both Taken in 1844*

Photography has long been seen as less relevant and appreciated than other artistic genres like painting, sculpture, dance, and theatre, even though photography had a huge influence on the works of artists like Manet and Degas. Portrait photography was barely recognized as high art when it first appeared in the 19th century, but instead was portrayed as an imitation of the art form as it was machine-made. In a comical parody of photography that was created in the late 1800s by a cartoonist by the name of Nadar, Mr Photography begs for a little space in the exhibition of fine arts, but Mr Painting yells at him and throws him out of the scene (Rosenblum 1984). The struggle by Alfred Stieglitz is not in vain when he introduced his portrait photography as artwork in an exhibition, which was rejected and questioned by the art museum director whether his works could be an art form. In the early 20th century, Man Ray went even further, giving up painting and focusing only on photography, where he discovered the value of reproduction in black and white (*National Museum of Art/Aperture, Man Ray's Man Ray West Palm Beach* 1994). Henri Cartier-Bresson studied painting, and he switched his medium to photography because he felt compelled to use a faster tool

than a brush to witness the scars left by the world (Squies 1997). Without a doubt, with the encouragement of Alfred Stieglitz, Man Ray, Henri Cartier-Bresson, and other pioneers in portrait photography, photography is now acknowledged as part of a broader definition of the visual arts. Artists depicted temperament, contentment, and distress throughout their sketches and paintings, yet in the 19th century, photography revolutionized the peer-reviewed study of facial expression. Scientists photographed and recorded what the eye could not distinguish instead of depending on artistic abstract ideas of the ephemeral face and emotional features. (Wade 2016, p. 1). Relatively low cost, the photograph has been another means for depicting a portrait, its uses being either clinical or artistic; wedding photography was commissioned for social events and many other commercial purposes. Nevertheless, portrait photography has played a central role in this tradition, which is tasked with the ambitious goal of capturing a subject's identity in a single shot image (Deguzman 2022). Traditional "portrait photography" is more formal and is usually done in a studio or outside with the subject looking directly into the camera. The composition may range from a close-up of the head of a person to a full body length. Photographers who take traditional portraits aim to capture the essence of the person in a single shot (Figure 6). Iconic figures could be people from culture, politics, arts, and sports amongst others. Lifestyle photography refers to portraits of less formal or more casual and typically tends to describe everyday situations and the environment of the subject. They can be taken both indoors and outdoors in a variety of settings (Figure 7). Furthermore, portrait photographs by Ami Vitali, Carolyn Drake, and Alex Wong precisely emphasized cultural background where the surrounding inclusion is evident in all of their works. Both history and cultural background contributed a large context behind the content of the arrested portraits, both as evidence of the present lifestyle and contemporary culture (Wong 2019). Meanwhile, conceptual portraits are an example of creative photography, a type used to illustrate an idea commonly known also as a self-portrait, expressed by the artists to see themselves as an artistic mean. Many photographers aim to capture internal states like emotion conceptually, it also gives them the freedom to "think outside of the box," visualizing elements to capture the subject identity. An important element is to understand your subject well to be able to anticipate their behaviour, mimics, and movements to capture that particular and special moment (Caputo 2023).

Figure 6. *Y.W. Alex Wong, Portrait-Photography (Close up), Nikon D800E, Nikkor (f.2.8) 80-200mm, C-Print, 160cm x 55cm. Mt. Hagen Festival, Papua New Guinea*

Figure 7. *Y.W. Alex Wong, Portrait-Photography (Inclusion of Environment), Nikon D800E, Nikkor (f.2.8) 24-70mm, C-Print, 150cm x 100cm.* (Top left & right) *Kashmir, and* (Down left & right) *Tibet*

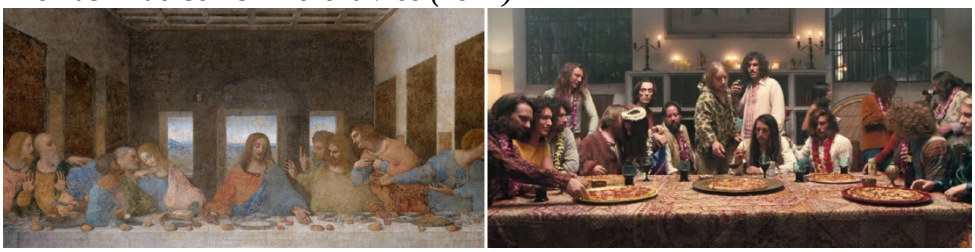
Portrait in Film and Animation

The optical paradox is the persistence of vision, and the phi phenomenon that underpins film illusion. When projected at the appropriate speed, the succession of still images on a strip of the film could indeed represent a continuous flow. Since Thomas A. Edison tasked his assistant William Kennedy Laurie Dickson to create the kinetoscope (1892), a machine that can portray moving images onto a screen and is widely considered to be the very first motion picture camera (Sklar et al. 2023). Edison proclaimed his prototype the "Kinetoscope," a combination of the Greek terms "kineto" (motion) and "scopos" (scope) (to watch). In the year 1891, the Kinetograph (camera) and Kinetoscope (viewer) were copyrighted and filed by Edison. The Kinetoscope was finished in 1892 (Library of Congress n.d.). However, the tedious and painstaking effort of motion picture making has changed dramatically more recently as digital camera has supplanted film. Meanwhile, cinematography is the art and technology of creating motion pictures (Britannica 2022). Rather than capturing a still image, cinematography entails framing a composition in motion. Even though both involve live models and actors, photography and cinematography have significant differences. Cinematography was concerned with the relationship and flow of shots. However, a single photograph can be deemed a complete work in its own right. A good portrait film requires not only a good actor, but also a good scene, lighting, camera lens, angle, and movement (Sklar et al. 2023). Portrait films attempt to capture the identity and story of a person or place, irrespectively of film style (Film noir, Italian neorealism, German expressionism, Documentary and Spaghetti western) or genre (Comedy, Adventure, Science fiction, Crime, Horror, Action, Romance, Drama, Fantasy, and Historical). It can be gradual, straightforward and conceptual like the cinematic portrait shots in the film, *Joker* (2019) directed by Todd Philips, which focuses on the Joker's psychological behaviour. Isolated, bullied and ignored by society, slowly Arthur Fleck (Joaquin Phoenix), the main character evolved into a criminal mastermind (Figure 8). We can notice that many great portraitures in art history influence and inspire the scenes in films and animations. Several film shots such as (Figure 9) Paul Thomas Anderson's *Inherent Vice* (2014) cinematic scene

referencing Leonardo da Vinci's notable painting *Last Supper* (1495-1498), Sofia Coppola's film *Marie Antoinette* (2006) with Jacques David's painting *Napoleon Crossing the Alps* (1800-1803), Terry Gilliam's memorable cinematic shots in *The Adventures of the Baron of Münchhausen* (1988) referencing Botticelli's renowned painting *The Birth of Venus* (1484-1485), etc. great films. Several animations also draw inspiration from great portraits in paintings, such as *Loving Vincent* (2017) an awe-inspiring animated portrait depicting Vincent van Gogh's works and his life. *Ruben Brandt, Collector* (2018) a mesmerizing mind-bending animated feature inspired by 13 portraitures from different artists. The animated sitcom *The Simpsons* (1989) often mocks global issues and contains wicked humour from various portraitures of well-known paintings and photographs.

Figure 8. *Screenshots from the Movie Joker (2019) Directed by Todd Philips, Joker Played by Joaquin Phoenix*

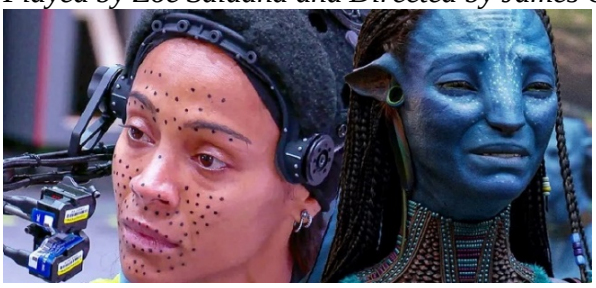
Figure 9. *(Left) Leonardo da Vinci's Last Supper (1495-1498) and* (Right) *Paul Thomas Anderson's Inherent Vice (2014)*



Hyper-realistic computer-generated (CG) living portraits are widely seen on movie screens nowadays. Several pioneering and high-definition facial capture systems enhance facial performance in the movie-making visual effects and animation production process, for example, Medusa, Anyma, Flux, and Mova helps to elevate and transfer the actor's facial expression to a computer-generated digital character. The characters such as Gollum (The Lord of the Rings, 2001-2003), Neytiri (Figure 10) and Jake Sully (Avatar, 2009 & Avatar: The Way of Water, 2022), Caesar and Koba (Rise of the Planet of the Apes, 2011), Davy Jones (Pirates of the Caribbean, 2006), Smaug (The Hobbit: The Desolation of Smaug, 2013), and Thanos (Avengers: Endgame 2019) are all possible on-screen with hyper-realistic facial mimic and expression, all thanks to such effective facial capture system and technology. Such technology and software changed the world. The way we perceive and interpret portraits, as well as how we define new boundaries in the art of cinematography, have all changed dramatically. At the

same time, there are more affordable and widely used facial software for public access such as Banuba Face AR SDK, Adobe Character Animator, IClone 8, Blender and CrazyTalk 8, which can be used on regular desktops, laptops, digital tablets and mobile phones.

Figure 10. *Facial Motion Capture Mirrors the Emotions of Neytiri, Avatar (2009) Played by Zoe Saldana and Directed by James Cameron*



The Advancement of Technology (New Media)

Facial Recognition

Whether in school, public, private activities, neighbourhood parks or personal devices, in innumerable and inexplicable ways, facial recognition technology (FRT) is infiltrating our lives (Raji et al. 2021). A question to start with is, what is facial recognition technology (FRT) and how does it function? An audit or evaluation is required in this description to assess the appropriateness of this specific technology to fulfil its purpose function within the specified context (Raji et al. 2021).

Portraiture has served as a means of representing identity as well as articulating quantified selves since its inception (Lupton 2016). Faces have always fascinated us, but they also reveal a lot about our personality, attitude, psychological state, and socialisation. Since the dawn of time, artists have attempted to depict this fascination, while scientists and academics have attempted to distinguish characters based on facial form and expression since the time of Aristotle.

Alan Sekula noted how photography, in the form of portraiture, has been used for the purposes of state surveillance since its inception. He claimed that in the 19th century, portrait photography was used to "establish and delimit the geography of the other and to clarify both the homogeneous look - the classifications - as well as the contextual case of delinquent behaviour and social pathology." (Sekula 1986). Particularly, portraiture in photography can serve as a useful form of data, when the information is extracted from the individual face. Not only did anthropometrics advocates like Alphonse Bertillon and Francis Galton invoke the concept of the face as visual data, but so did critics of photography and its status as an art in general. Portraits are increasingly being used to prepare surveillance and authentication systems due to their ability to extract faces and people's identities. Portraiture has been used in the development of algorithmic technology to access a person's age, gender, race, emotional state, sexual orientation and political

preference (Hristova 2021, p. 74). In 1857, Lady Elizabeth Eastlake indicated portraiture as the balancing act between representation and quantification (Eastlake 1981). Like fingerprint and voice recognition, facial recognition is a form of biometric technology, which verifies and authenticates a user's facial identity in photos and videos (real-time). This biometric information may infringe on citizens' rights, which could be used as a surveillance tool; consumer advocates, on the opposing hand, are in favour of restricting the implementation of (FRT) for safety purposes. There is little doubt that (FRT) continues to pose many cyber threats, particularly when used in public spaces or locations; if used effectively, it will eliminate any likelihood of anyone concerning one's everyday routine privately and anonymously (Nakar 2017, p. 94).

Facial Recognition Technology (FRT) includes:

1. Facial disclosure – The camera detects and arrests the presence of a face from the user via photo or video mode. The main purpose is to determine the position, appearance and authentication of the user.
2. Facial examination – Face detection and recognition software maps the face and calculates the distance from its most important features such as facial characteristics and individuality. These calculations are later disseminated into a set of related arithmetic known as a "faceprint" or "face signature." The face print is added to a database of identification for governmental or private companies (Boneh et al. 2013).
3. Facial identification – The face signature is matched to a database and an algorithm that quantifies known faces. Such processes help to determine the identity of an individual in either a photograph or video. The more diverse the set of photos embedded in the system, the more precise the results.

The popularity of Facial Recognition Technology (FRT) stems from its proven fiscal benefits, including:

a) Increased surveillance: Face recognition technology has the potential to reduce crime while also improving safety and security. Even after several years, it aids in the identification of criminals and missing persons. Enterprises are secured from theft and illegal access to office compounds thanks to face recognition software.

b) Simple assimilation: The majority of security software is compatible with most of the new biometric identification solutions. One requires no prior computational expertise to begin.

c) Effectiveness: Heretofore, a person would perform the inspection process manually. It was laborious and unproductive. One can track the presence of staff members and other visitors using facial recognition technologies.

d) Efficient organization: Face recognition systems are entirely automated. As a result, maintaining records and keeping up with everyday activities is much simpler.

As previously stated, face recognition provides numerous possibilities for companies and other entities. Although it continues to possess several discrepancies and flaws, its competencies in the present artificial intelligence digital industry are projected to expand (Traichuk 2022).

The Use of Artificial Intelligence to produce Portraits of Nonexistent Individuals

In the beginning, humans used computers to perform mathematical operations; this tool, like computers and networks later, quickly became an essential tool that humans take for granted in our daily lives. Looking back through history, the emergence of each new technology has resulted in the rise of a group of "technological innovators," resulting in an entirely novel gap between the rich and the poor as well as a new path for social development. Those who cannot keep up will be squeezed into their initial fields and compelled to work harder during this transitional period. Although there will undoubtedly be people who encounter some hardship, the pace at which emerging technologies drive social development will generally benefit humanity as a whole. At this point, we should look at the context from "AI to replace humans" to "AI to strengthen humanity." Surely, there will be challenges ahead in different eras and situations when AI is further developed. On the other hand, science fiction novels all share the same concern: "Is it possible that AI will overtake humans and become the most powerful entity on Earth?" Overtaken by a more prominent (artificial intelligence) species? Surely, this is humanity's deepest fear. In this regard, the current learning consensus is that AI, which is based on machine learning and algorithms, is still merely a tool that should be managed by humans. Instead of letting the AI decide everything in a black box, the engineers determine how the algorithm performs, how to utilize the data, and what language to use to articulate it. Therefore, even if the AI demonstrates human-like emotional patterns as a result of the language model's configuration, which includes knowing how to comfort the user when the user gets upset and replies cutely, it is merely a program arrangement, because AI is unable to defy the inputted command. The most significant distinction between AI and humans, in this regard, is that humans have autonomous consciousness and can make emotional and moral judgments. This is the core value of being human.

Is Artificial Intelligence the next leap in the evolution of the Art Movement? AI-generated art lets us experience a new level of unconventional creativity, blurring the distinction between machines and humans. Nowadays, AI systems are capable of producing multifaceted portraits in various styles, from cubism to modern to pop art. All AI systems require are keywords and prompts. The creative art world is exuberant with possibilities.

However, just as how photography is first introduced as art, the art world alienated and doubted its position, today, some continue to argue that computer or AI-generated art is neither art nor creative (*Christie's Education* 2019). With the advancement of technology, the subject of portraiture was created and completed

not "in time," but "on time," as the production duration shortened to a split second, whether it is in the form of painting, photo-realism or real-time.

The portraits created by Mario Klingemann using AI technology demonstrate that artists continue to experiment and find the sublime beauty in the imperfect portrait creation from the marriage of the two disciplines (art and technology) as one. *Memories of Passerby 1* (Figure 11) have no registry of a database. Mario Klingemann created and trained an AI brain that creates new portraits in real-time, pixel-by-pixel. The changing portrait flow does not follow a predefined sequence but is the result of the AI interpreting its output; this means that no images will ever be replicated while the AI is actively running (Sotheby's). Another notable artist and engineer, Scott Eaton, develops and uses artificial intelligence to render his drawing and animations into figurative (Figure 12), digital imaging, and abstracted sculptural forms. Rather than using AI as a creating agent that "creates art" spontaneously, he prefers to use AI as the "art collaborator" in the emerging field of technology to enable the creative potential accessible to the human artist (Artfixdaily 2019). Meantime, other esteemed individuals such as Gene Kogan, Mike Tyka, Robbie Barrat, Ahmed Elgammal, and Stephanie Dinkins use AI technology as an artistic medium and tool, to generate unimagined portraits and distinctive figurative artworks.

Figure 11. *Mario Klingemann, Memories of Passerby Multiple GANs, Two 4k Screens, Custom Handmade Chestnut Wood Console, which Hosts AI Brain and Additional Hardware, 2018*

Figure 12. *Scott Eaton, Portrait Study – Pavel 1, Zbrush*

In 2019, the engineering team at Nvidia Corporation refined the Artificial Intelligence (AI) technology to create portraits of people who don't exist by using preliminary faces as data input to generate new faces with computational algorithms, to create new features of the new individual (Figure 13). It is very different from the concept of transformation or morphing techniques, which draw information from the preliminary visual reference. Using style transfer research, the authors (Nvidia Corporation's Tero Karras, Samuli Laine, and Timo Aila) suggested alternate generator architectural features for adversarial networks with generative algorithms. This one-of-a-kind design enables intuitive configuration control of the formation as well as instantaneous, unrestricted disconnection of elevated features (e.g., gesture and personality while directed on human figures) and dynamical variability all across the image features (e.g., freckles, hair) (Karras et al. 2019).

Figure 13. *A Style-Based Generator Architecture for Generative Adversarial Networks, by NVIDIA Corporation, 2019*

On the other hand, AI portraits called magic avatars are portraits (Figure 14 below) generated by the Lensa app. Lensa, which is owned by Prisma Labs, lets consumers upload pictures of themselves with a fee and retrieve images of themselves in various fanciful parameters within minutes. The app elicits billions of images and other public information from the web while processing them through Stable Diffusion, an open-source algorithm. This popular app is now used by millions of people from all walks of life to create instant artistic portraits in different styles, without needing a painter or artist to do so.

Figure 14. *Example of Portraits Generated with Lensa's Magic Avatars App, Developed by Prisma Lab*

At the same time, Foto's AI face generator, which is integrated with AI and deep machine learning, allows users to generate highly realistic faces from scratch in seconds. Users can simply describe the keywords such as gender, age, hairstyle, accessories and other characteristics. Midjourney and other low-cost AI programs and generative 2D software can generate images from text descriptions. Like OpenAI's ChatGPT, DALL-E, Stable Diffusion, Jasper Art, Photosonic, Starry AI, NightCafe, Artbreeder, and Dream by Wombo, users can install the program on a smartphone and use it instantly by typing keywords and descriptions to create portraits without having to take a photo of anyone.

Conclusion

Today, the practising and learning curve of art, which requires technology, could be harder for those who barely use a computer to produce artwork, such as a pure sculptor or painter who concentrates on perfecting skills. There remains room to improve; constant changes and modifications of digital art require the understanding of technologies, which in itself requires an entirely different mindset and perception. Artists who have embraced the fusion between art and technology today are highly imaginative in artistic content creation whether it is on the screen or by projection in the air and space. Regardless of the advancements of new AI technologies, there are certain setbacks. Choice and partisanship are top of the agenda because all current AI systems rely on the input and command of the creator and the information they are fed. Nonetheless, as time moves forward, the artistic creation of portraiture will surely become more spellbinding and magical because creativity is all about the capability to correlate, generate new synthesis, spark new ideas, and new metaphors, concerning shreds of evidence, philosophy, theory and history. In short, the art of portraiture creation, both in the past or near future, always depends on the creator and their choice of working tools, whether it is with paints, cameras, computers, facial capture systems or artificial intelligence generators. Just as the philosopher, Immanuel Kant mentioned, "Man has the ability to create himself". Great portraiture, whether from art or media aesthetics, always leaves an impact that mesmerizes the viewers and stands the test of time.

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