SINEKTIKA Jurnal Arsitektur

p-ISSN: 1411-8912
e-ISSN: 2714-6251
http://journals.ums.ac.id/index.php/sinektika

REVISITING INDONESIA NEW AIRPORT BUILDINGS: TOWARDS BUILDING SYSTEMS INTEGRATION

Intan Findanavy Ridzqo
Department of Architecture
Insitut Teknologi Indonesia
Tangerang Selatan, Banten,
Indonesia
intan.findanavy@iti.ac.id

Hermawan Indra Dwiyanto
Department of Architecture
Insitut Teknologi Indonesia
Tangerang Selatan, Banten, Indonesia
hermawan.indradwi@yahoo.com

ABSTRAK

Momentum pembangunan infrastruktur biasanya memperlihatkan kemajuan pengetahuan dan teknologi yang diterapkan pada rancangan dan hasil yang terbangun. Pembangunan yang terus dilakukan selama dua dekade terakhir di bidang transportasi, termasuk di dalamnya adalah pembangunan bandara di Indonesia. Strukturnya yang luas membuat bandara ini memerlukan penanganan khusus dalam sistem operasi bangunan, yang membuatnya berbeda dengan jenis bangunan lainnya. Perencanaan yang matang dan terintegrasi dari komponen-komponen bangunan diperlukan agar desain bangunan menjadi efisien dan efektif. Minimnya penelitian di bidang arsitektur dengan objek fungsi bangunan bandar udara membuat penelitian ini diharapkan dapat menjadi tonggak sejarah, dan pembelajaran bagi para perancang untuk dapat melangkah lebih jauh dari praktek yang selama ini dilakukan. Penelitian ini dilakukan dengan mengidentifikasi sistem utama, subsistem, dan elemen-elemen pembentuknya pada bangunan CGK, KJT, YIA, DPS, BPN, PKY, dan MDC melalui observasi sumber-sumber domain publik, kemudian dianalisis untuk menemukan kemiripan antar bangunan bandar udara. Strategi integrasi yang paling mudah dan umum dilakukan adalah dengan menggabungkan komponen mekanikal atau non-struktural dengan komponen struktural (E-M), sedangkan strategi integrasi yang paling sulit dilakukan adalah dengan menggunakan material struktur yang memiliki banyak peran sekaligus (S-E-M-I).

KATA KUNCI: bandara, bangunan bentang lebar, integrasi sistem bangunan, tingkatan integrasi, S-E-M-I

The momentum of infrastructure development usually shows the progress of knowledge and technology applied to the plans and results that have been built. The steady development over the last two decades in the field of transportation, which also includes the airport in Indonesia, has been carried out. Its vast structure makes this airport require special handling in the building's operating system, which makes it different from other types of buildings. Mature and integrated planning of building components is required for building design to be efficient and effective. The scarcity of research in architecture with objects of airport building functions makes this research expected to be a milestone, and learning for designers can go further beyond the practice that has been done so far. This research is conducted by identifying the main system, subsystem, and its forming elements on CGK, KJT, YIA, DPS, BPN, PKY, and MDC buildings through observation of public domain resources, then analyzed to find similarities between airport buildings. The easiest and most common integration strategy is to attach mechanical or non-structural components to the structural component (E-M), while the most difficult one is a structural material that plays multiple roles at once (S-E-M-I).

KEYWORDS: *airport, long-span building, building system integration, level of integration, S-E-M-I*

INTRODUCTION

The territory of Indonesia extends from Sabang to Merauke, consisting of both large and small islands separated by the ocean. As a gift, because the land and the ocean hold great potential for natural wealth, this geographical form presents its challenge, connecting the natural and human resources to be able to fill each other's needs. Nowadays, non-physical exchanges are becoming much easier online through an internet connection. However, it cannot be denied that physical connectivity is still a primary need, so the physical infrastructure still needs to be continuously filled.

In the last more than two decades, the government has been intensively working on several airport projects as infrastructure for transportation. Many new airports are being established to connect more areas of the city or district with a mode of air transportation that makes the process of moving both people and goods faster. Just as aircraft are the highest-tech transport mode among all other modes of transport, an airport is also regarded as a special luxury. An airport is a place where passengers wait before boarding a plane, making it part of the passenger experience of traveling on an airplane.

Airport buildings, like the types of buildings for other transport functions, serve to accommodate large numbers of users and connect users with other public transportation modes. The main structure of the airport buildings generally uses a long-span structural system to cover wide spaces underneath them. Its vast structure makes this airport require special handling in the building's operating system, which makes it different from other types of buildings. Mature and integrated planning of building components is required for building design to be efficient and effective.

Rush categorized four main building systems: building structure (S), building envelope (E), mechanical and electrical (M), and interior space (I) (Rush 1986). The four can be integrated into each other to create two, three, or even four functions in one element. The element can take the form of a material or a machine (Rush and Stubss n.d.). The importance of integration is aimed at achieving efficiency and effectiveness in terms of time, materials, costs, environment, space, passive systems, adaptive reuse, and future expansion (Norford and Xing 2001) The attempts to integrate building components show designers respect for the optimal use of the elements used to shape the building. The process of planning integration requires multidisciplinary work (Flager and Haymaker 2007), not just architects, because the ultimate goal is to obtain high performance from the building.

The momentum of infrastructure development usually shows the progress of knowledge and technology applied to the plans and results that have been built. Over time, these advances have significantly contributed to the ongoing infrastructure development in Indonesia today. The scientific and technological developments that are taking place today have greatly influenced the outcomes of the infrastructure development process, including airport buildings. The airport building is a symbol of a gateway into a region, so the technology used is very helpful in creating a building that can hinder progress in the region.

This research is being carried out to identify the components of the airport building and possible integrated forms so that more effective and efficient building designs can be produced. The scarcity of research in architecture with objects of airport building functions makes this research expected to be a milestone, and learning for designers can go further beyond the practice that has been done so far.

THEORETICAL FRAMEWORK

A building consisting of the systems can be sorted from the main system described by Rush with S-E-M-I, to each system consisting of the sub-systems below it. Rush outlines each major system more openly and not so specifically. Rush tends to give a general picture, for example, of a structural system consisting of structural members that can withstand earthquakes, winds, earthquakes, and living loads on buildings, or an interior system that consists of ceilings, walls, and space contents. Each subsystem or component, type of material, or machine is identified as having a role, whether it acts individually or against another subsystem (Rush and Stubss n.d.). For that, the subsystem is proposed by the author based on related literature (Table 1).

Table 1. The theoretical framework of building system components

Building the main system (Rush 1986)	Subsystem	System Component	Reference
S (Structure)	Substructure	Foundation	(Ching, Onouye, and Zuberbuhler 2013) (Dong, Zhao, and Xing 2012)
	Superstructure	Spanning system (horizontal)	
		Support system (vertical)	
		Joint, construction	
E (Envelope)	Vertical building envelope	Main wall	(Lovel 2013)
		Secondary wall	
	Horizontal building envelope	Roof	
M (Mechanical)	Thermal comfort	Cooling	(Lechner 2014)
	Visual Comfort	Lighting	
I (Interior)	Ceilings	Interior form	(Brooker and Stone
	Decorations (atmosphere)	Nuance	

2007) (Coles and House 2007)

Structural systems in buildings are generally divided into lower structural subsystems and upper structural subsystems (Ching et al. 2013). The underlying structural subsystem of the foundation that passes the load of the building to the ground, is also part of the formation of the basement, along with the vertical diaphragm wall. The upper structural subsystem of a wide-angle building is a structural sub-system that covers spaces, consisting of horizontal shutters proceeding to the vertical support, which is also actually a small subsystem in which there are elements of structural members assembled with certain connections (Dong et al. 2012).

The structure of the building is a frame that is covered with a building envelope that shapes a space underneath (Lovel 2013). In general terms, the envelope system for any building typology can be divided into vertical and horizontal envelopes. However, in some types of long-span building structures, building envelope systems can act simultaneously as structural systems that support loads. For instance, shell and membrane structural types fall under the category of form-active systems, in which both vertical and horizontal envelopes are a unity. To reduce the thermal impact of sunlight, a vertical blanket can usually also be equipped with a secondary envelope on the outer side.

After a building structure is ready, it cannot be used without being equipped with a mechanical and electrical system. One of the purposes of this system that should be run during the building's operational life is to create comfort for users active in it. Comfort can be divided into visual and thermal comfort (Lechner 2014), Rush also adds that acoustic comfort is included in this system. Both can be achieved proportionately by combining passive and active strategies, especially optimizing energy savings (Stevanović 2013).

The interior system consists of finishing and furnishing. Both subsystems were designed to give expression and character to the interior space as well as the nuance of space (Coles and House 2007). Its components can be ceilings, floors, furniture, and decoration (Brooker and Stone 2007).

Integration of the main system of one building with the other forms a type of integration of two systems, for example, S and E, three systems, such as S – E – I, and four integrated systems. More and more integrated systems reflect the results of an efficient and effective design (Figure 1).

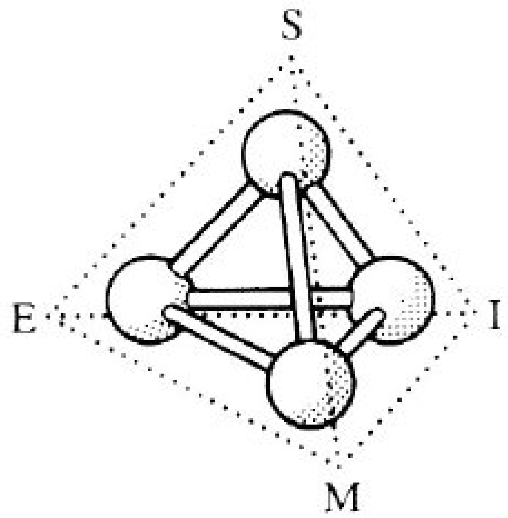

Figure 1. Schematic of building system integration. (Source: Altomonte and Luther, 2006).

METHODS

The building is a unity of the various integral sub-systems of its composition with complex configurations. Over time, every new building has to be designed responsibly so that it can efficiently use various resources to shape itself amid increasingly limited resource conditions. So is the case with the increasing number of airports built in various regions of Indonesia that need to be analyzed for a moment against the systems in them to determine whether the design results have been efficiently reflected in the integration of one with the other. For that, the methods developed in this research against previous research that inspired it are (Szolomicki and Golasz-Szolomicka 2019):

- Collect all the information through articles that inform about the construction of new airport building projects
- Collect a variety of general building information, consisting of the name of the building, photos, location, scale of service extent of the floor, and year of construction, obtained from news articles about the new airport building projects
- Identify the main system, subsystem, and its forming elements on each building object through observation of photos and news articles, then analyze to find similarities between building objects arranged in the common table
- Analyze the integration between subsystems that are directly integrated with other sub-systems on each building object by observing various photos of building objects. The results of this analysis are

then assembled into an integration diagram with the website-based mindmap software, https://miro.com/

- Draw conclusions, based on common tables and diagrams, about the form of integration that has been carried out on the new airport building and use them as a learning tool for the future

RESULT AND DISCUSSION

The New Airport Buildings

The steady development over the last two decades in the field of transportation, which also includes the airport in Indonesia, has been carried out. Airport projects are generally carried out with the objective of both increasing capacity and creating new flight destinations. In the airport complex, there are several types of buildings, including terminal buildings and parking and cargo buildings.

From the initial search results, it is known that there were as many as 12 airport construction projects in Indonesia in the period from 2007 to 2023. Besides, there are at least five other projects still under construction. To narrow the number of research and further analysis objects related to the identification of building components and their integration, the list of initial findings was then selected based on the criteria that airport buildings had been completed, had served domestic and/or international flights, and had passenger terminal floor area of more than 10.000 m^2 (Table 2).

Table 2. List of selected airport buildings according to the criteria of the research object.

Object No.	Airport Name	Building Photo	Location	Class	Floor Area of Passenger Terminal (m^2)	Completion Year
1	Soekarno-Hatta International Airport (CGK) Terminal 3		Tangerang, Banten	Internasional Class 1	331.101 (Silvita Agmasari 2017)	2009-2011
2	Kertajati (KJT) Airport		Majalengka, Jawa Barat	Internasional Class 1	121.000 (Biro Komunikasi dan Informasi Publik Kementerian Perhubungan Republik Indonesia 2018)	2017
3	Yogyakarta Internasional Airport (YIA)		Kulon Progo, Yogyakarta	International	219.000 (Anon 2021)	2020
4	I Gusti Ngurah Rai International Airport (DPS)		Badung, Bali	Internasional Class IA	265.891 (DEWAN PERWAKILAN RAKYAT REPUBLIK INDONESIA 2019)	2017
5	Internasional Sultan Aji Muhammad Sulaiman Sepinggan Airport (BPN)		Balikpapan, Kalimantan Timur	Internasional Class 1A	11.000 (Anon 2013)	2014

6	Tjilik Riwut Palangkaraya Kalimantan Tengah (PKY)		Palangkaraya, Kalimantan Tengah	Domestic Class 1B	29.124 (Yunita Amalia 2019)	2019
7	Sam Ratulangi International Airport (MDC)		Manado, Sulawesi Utara	Domestic Class 1B	57.296 (Anon 2022)	2021

Structural System

The main structural system of a long-span building is generally divided according to the position of the structural systems, which are the lower and upper structures (Table 3). The substructure consists of the foundation, basement, and soil retaining wall, while the upper structure refers to the building body and roof. Unfortunately, the substructure of the seven research objects is not known. The documentation of the construction process is not available in the public domain, so it makes observation and learning of the system of the underlying structures difficult.

Table 3. Identification of components on structural systems.

System component			Object no.						
			1	2	3	4	5	6	7
Superstructure	Support system	Large vertical concrete column		v	v		v	v	v
		Large-size sloping concrete columns	v						
		Large steel pipe column				v			
	Span system	Space truss system with steel	v		v	v	v	v	v
		Space truss system with steel material with a combination of cables		v					
	Construction	Welded		v	v	v	v		
		Bolted connection			v				
		Pin		v					
		Mero ball	v						v

This type of space truss system with steel material is used on the entire airport as a wide roof structure. This type makes it possible to create a wide space without a column in the middle while being flexible enough to form the geometry of a wavy roof. Meanwhile, the space truss on the roof of the KJT airport has a variation in the use of cable material in the distribution of the tensile force between the members of the structure.

Span system with support system connected by connection, the most common and easiest method is welding technique. At the roof connection point at YIA Airport using a combination of bolted connections. On the KJT, there is a pin connection that connects the steel rod element to the cable, allowing the moment release of the forces in various directions, and accommodate lateral forces like earthquakes and winds (Figure 2).

Figure 2. The joint construction of the KJT roof uses a combination of welded and pin.

Envelope System

A building envelope is a shield covering a building from the vertical side of the ground to the horizontal side of the roof. In long-span buildings, the walls as a vertical building envelope are often the same material and mechanism that continue to form a horizontal blanket in the roof part, for example in the type of folded plate, pneumatic, and arch structures.

Nevertheless, these seven research objects show clear differences between vertical and horizontal envelopes. (Table 4). The vertical envelope is divided into the primary and secondary walls. The main envelope materials are bricks and glass. The brick walls are partially used in terminal buildings to safeguard important rooms, such as control rooms. All buildings use glass material as the primary building envelope. Glass material lets passengers still have orientation while in the building, especially toward the runway and exit. Meanwhile, on the other side which does not require a visual outward direction, brick is more often used. In the KJT drop-off area, a secondary wall made with perforated metal provides a shade in front of the curtain wall behind (Figure 3).

Table 4. Identification of components on the building envelope system.

Type of material			Object no.						
			1	2	3	4	5	6	7
Vertical	Main	Brick	v	v	v	v	v	v	v
		Curtain wall	v	v	v	v	v	v	v
	Secondary	ETFE		v					
		Perforated metal							v
Horizontal	Metal		v			v	v		v
	ETFE tensile membrane			v	v				

Figure 3. Perforated metal shade in the drop-off area of KJT airport.

At the horizontal envelope, the long-span roof structural frame is enclosed with a metal material. At the KJT airport, some areas of the roof are combined with transparent ETFE membrane tensile to allow natural sunlight to fenestrate into the interior. Meanwhile, at YIA airport, this type of material aesthetically provides shade for passenger drop-off. The use of curved transparent roofs is combined with the configuration to form a very clearly visible *batik kawung* motive. From the point of view of the human eye, the roof is also supported by the appearance of branch-like columns (Figure 4).

Figure 4. The roof at the drop-off area in YIA airport with *batik kawung* configuration.

Mechanical-electrical System

The mechanical and electrical systems include all the mechanization and electrification equipment needed to operate the building. However, the limitation of carrying out direct observation makes the explanation limited to how the space obtains illumination and warming. Both components of the system are divided into natural and situated systems (Table 5).

Table 5. Identification of components on mechanical and electrical systems.

System component			Object no.						
			1	2	3	4	5	6	7
Air cooling	Natural	Natural cooling in the lobby room	v		v	v			
	Situated	Central air conditioning in the hall and check-in	v	v	v	v	v	v	v
		Central air conditioning with regular ducting on the corridor and boarding		v	v	v			
		AC cassette and standing on the corridor and boarding	v			v	v		
Lighting	Natural	Natural light sources through glass walls	v	v	v	v	v	v	v
		A source of natural light through the skylight on the roof		v		v			
	Situated	Artificial lighting is functional	v	v	v	v	v	v	v
		Special artificial lighting		v			v		v

The portion of the natural air conditioning system is still used quite dominantly in the lobby area at CGK, YIA, and DPS airports. Natural conditioning in the open lobby area is large enough to cover the entire floor of the terminal building, which is a good strategy to suppress building energy consumption. Furthermore, the time intensity of visitor occupation in this area is short, so the use of artificial air cooling is not a necessity.

Meanwhile, the entire artificial air cooling system in the interior terminal building uses an AC cassette with an AHU. However, the specific difference is the diffuser, which is the ordinary ducting grill, and the jet nozzle air diffuser. The cold air distribution system using the ducting grill is placed in a room with a smaller volume because the utility has to be closed with a lower ceiling, for example, in the corridor area. Meanwhile, the jet nozzle diffuser is widely used in more open areas, as it can be placed lower so that cold air spray can be more experienced by visitors. This component is widely used in the hall area for check-in and boarding areas (Figure 5).

Figure 5. Air conditioning grill ducting in the corridor and jet nozzle air diffuser at main hall CGK.

The source of sunlight is still dominantly used to illuminate indoor spaces, especially in areas with curtain walls. In addition, thanks to the transparent material on the roof for the hall room at KJT airport and the lounge and drop-off area at YIA airport, make the interior bright. However, the glass color at the KJT airport looks brighter than the darker YIA airport (Figure 6). Meanwhile, functional artificial lighting is used throughout the interior. Some artificial lighting consists of a spotlight and a strip light.

Figure 6. The transparent roof material at KJT and YIA.

Interior System

The components of the interior system that can be observed are the ceilings and interior spaces (Table 6). There are ceiling components usually intended to close the roof frame and utilities that are underneath it that are not so attractive to be exposed. However, the absence of ceiling covering exposes the main roof frame of the building, as at KJT, DPS, and BPN airports. Meanwhile, the interior spaces are lit by artificial lighting. Small lights or strip lights are placed to expose structural components, such as columns and roof frames.

Table 6. Identification of the components of the building interior system.

System component		Object no.						
		1	2	3	4	5	6	7
Ceiling	Open roof structure without closing with ceiling fields		v		v	v		
Nuance	The atmosphere of the interior is specially designed by placing the lighting at a certain point	v	v	v				v

Main Building Systems Integration

The materials, machines, and types of systems on the research objects identified above are components of any building system and subsystem. A component can run independently without dependence on other components in another main system and can be interdependent with components within the same main system. For example, the type of connection on the roof frame in the main structure system does not depend on the other components in the primary cover system, mechanical and interior, but plays an important role in integrating the components within the main system of the structure, namely the support system and the span system. Rush's integration, however, is a component of a main system that is integrated with other components of another main system. Mapping the integration of components in the main system and sub-systems of building structures is presented in Figure 7.

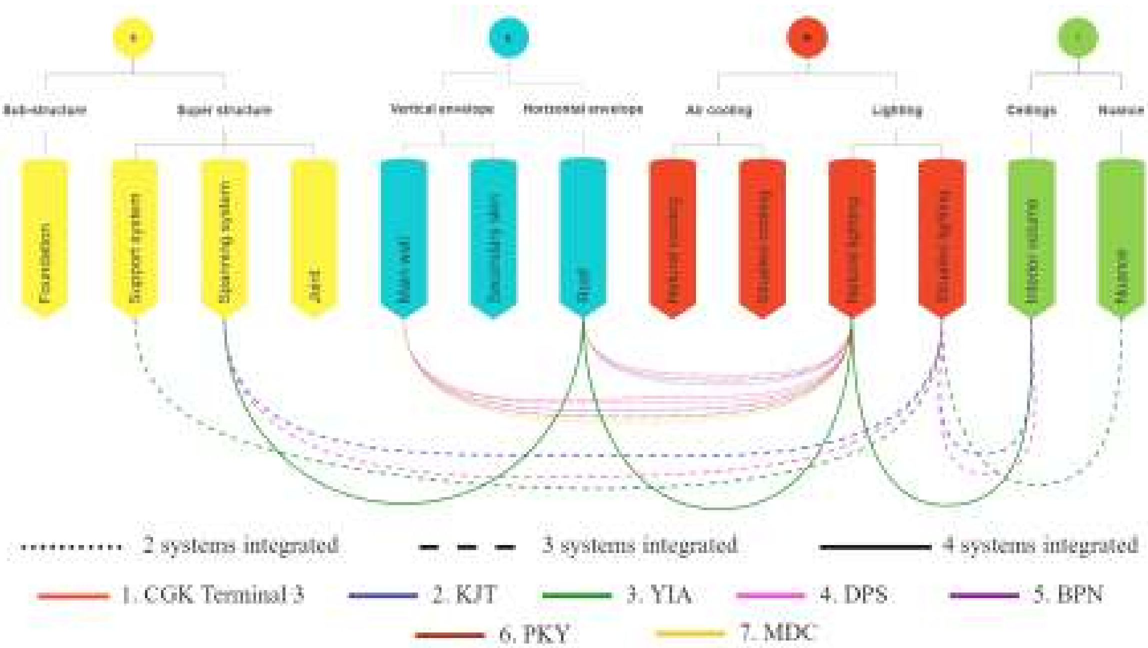

Figure 7. Mapping of the building's main system, subsystems, and components integration at the seven airports.

The first form of integration is the integration of two systems, namely E-M, which occurs throughout the object (Figure 8). The components of the main envelope system, namely the transparent walls, and roofs, are integrated to create natural lighting. The two forms of relationship based on the five levels of Rush integration (Altomonte and Luther 2006) are the fourth level, i.e., meshed. The transparent elements that are in place, in addition to serving as a building envelope, are also used to bring sunlight into the room. When obtaining transparent technical data or material specifications, this integration relationship can be even better because of not only lighting but also artificial heating. Transparent materials with smaller thermal absorption values reduce the thermal exposure to the sun so that the interior is not too hot and the energy load to cool the room by artificial heating systems can be lower.

Figure 8. Implementation of two E-M system integrations.

The next form of integration is the integration of three systems, namely S-M-I, which takes place in the main passenger hall area of the KJT and YIA airport terminals as well as the DPS airport reception area (Figure 9). The level of integration between S and I is unified, i.e., the curved ETFE material can be felt from the interior. While the M level of integration with S and I is touching, artificial lighting adheres to the structure so that the volume of the curved ceiling space is increasingly highlighted with artificial illumination. Artificial lighting components are the most common of the three main systems. However, what is happening is that artificial illumination is conditionally located to expose the elements on the widescreen roof structure, which then creates the nuance of a crowded and technologically sophisticated interior space. The variety of widest stretch structures and vertical supports basically have a more exploratory configuration of elements, such as horizontal, standing, and diagonal, since each element serves to support large accumulative loads distributed to smaller elements by making the tensile and compressive properties.

The integration of the four main building systems, S-E-M-I, has been quite well implemented in the reception and drop-off areas of the YIA terminal building (Figure 10). The systems S, E, and I are integrated and unified, while M and the other three are touching. The curved ETFE material is shaped into an oval dome roof, arranged following the *batik kawung* pattern, and acts as both a structural element and a horizontal envelope. The material surface has a special finish that can reflect light, which is exploited by placing strip lights around it, making the roof an icon, especially at night.

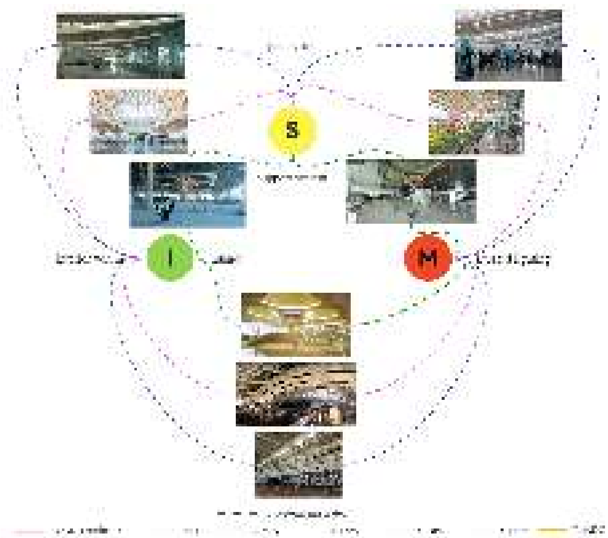

Figure 9. Implementation of three S-M-I system integrations.

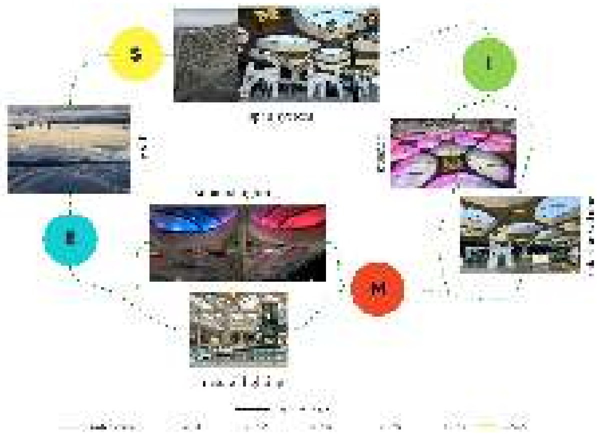

Figure 10. Implementation of integration of four S-E-M-I systems in the YIA airport passenger terminal reception area.

CONCLUSION

The integration of the building's main system can be identified through the sub-system and its smaller components in one main system (S, E, M, and I) and its role over others in the other main system. Relationships between subsystems and components are expressed in five levels of integration by Rush. Nevertheless, the subsystems and components within a major system are supposed to be integrated.

In the seven airport buildings in Indonesia, there are at least two main systems that are most easily integrated, namely an envelope (E) and a mechanical (M). The role of the roof and wall envelopes with high technical specifications in resisting solar thermal absorption will make the performance of artificial cooling subsystems and the energy used suppressible. The integration of the three systems that have been implemented in the design of the airport building is the structure (S) that is highlighted with the artificial lighting system (M) thus creating interior nuances. (I). The last, and highly anticipated, is the integration of the four systems. Exploring the envelope (E) as a structure (S) creates a dynamic volume of space inside (I), and adding lights makes this integration effort more visible.

The implementation of the highly sought-after integration needs to be assessed by the level of Rush integration. The easiest and most common attempt is to attach mechanical or non-structural components to the structural component, until the most difficult is unified, which is a structural material that plays multiple roles at once. Thus, the selection of materials that are structural or can support structural loads is the key to achieving optimal integration.

Besides, integration efforts are not just happening on the entire building floor. The passenger terminal building is divided into large areas, ranging from the reception and drop-off area to the main passenger hall area, the corridor, and other services.

Implementation of integration is not limited to the entire building, although, of course, it's the best. However, with an effort to integrate in one area and optimize it in another, it is also a good strategy to start.

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