Abstract—Building energy simulation plays an important role in the design process by predicting building performance. Yet practitioner designers often feel frustrated during preparing simulations, if they are not sure of design variables of an Energy Conservation Measures (ECMs) requiring accurate information about building and systems. To help practitioners, this paper provides a guideline to select ECMs, evaluation simulation tools, and detailed inputs for modeling of ECM at each building design phase as a format of Level of Detail (LOD).

Index Terms—Energy conservation measure, level of detail, energy simulation, building modeling guideline.

I. BACKGROUND AND OBJECTIVE

A global warming caused by an increasing use of fossil fuels begins to cause a serious environmental problem. Buildings take up to 30% of national energy consumption as in lighting, electrical equipment, heating ventilating and air conditioning (HVAC) system, and refrigeration systems. To effectively and efficiently regulate building energy use, it is important to select appropriate Energy Conservation Measures (ECMs) in building design process, rather than to add some actions after construction. In a design stage, building energy simulation is a useful tool to analyze the energy performance of a building model containing ECMs. Most energy simulations, however, require an expert level of system knowledge as well as simulation knowledge. It is, thus, hard for practitioners to actively employ building energy simulations during design process.

II. RESEARCH PROCESS

The aim of this study is to suggest a guideline that improves a use of energy simulations in each design phase. This study proposes what simulations are appropriate to capture features of ECMs and when Level of Detail (LOD) of each ECM starts being discussed and confirmed in the design process. Fig. 1 briefly elaborates how this study has proceeded.

III. BUILDING DESIGN PHASES

The building design process can be divided into phases in Table II. Also, it elaborates primary tasks of each design stage in order to identify when LOD starts to be discussed and confirmed.

IV. ENERGY CONSERVATION MEASURE (ECM)

Factors affecting energy consumption of a building can be divided into architecture, MEP, and controls as shown in Fig. 2. Architectural design can be classified into mass and layout plan, building envelope and materials. MEP design can be classified into heat source, air conditioning system, lighting system, renewable energy system, equipment. Controls mean an operation method of buildings and equipment such as scheduled ventilation and night purge that means ventilating. Most ECMs in this paper were selected based on [1]-[7].

Fig. 1. Process of the research.

Examine a major scope for design process

Research of ECMs for building and MEP

Analysis of LOD for ECMs

Investigation of energy simulations

First, we have examined major tasks at each design phase and formulated a basic framework of the design process based on interviews with design engineers. Next, we have explored literature and selected ECMs available in the market and then classified them into passive measures applied to a building and Mechanical Electronic and Plumbing (MEP) measures. In the third step, LOD of each ECM has been factorized and then analyzed in which design phase the LOD can be decided. Lastly major simulation tools that have a sufficient capability of evaluating ECMs in each design stage in terms of algorithm and usability have been investigated. The final artifact of this study is well described in Table I. Readers can find a useful information concerning a choice of ECMs, evaluation tools, and information availability of the ECM at each design phase.
| ECM                                                                 | Simulation            | Object     | Sub-Object          | LOD                                                                 | PS | SD  | D   | CD         | Cons/ Ocup. |
|-------------------------------------------------------------------|-----------------------|------------|---------------------|---------------------------------------------------------------------|----|-----|-----|------------|-------------|
| Shading and daylighting optimized by surroundings                 | EnergyPlus, eQUEST, TRNSYS | Mass       | G&T                 | Placement, Area, Volume, Floor, Height, Orientation                |    |     |     |            |             |
| Building mass minimizing envelope area and taking advantage of solar gain and heat loss | EnergyPlus, eQUEST | Mass       | G&T                 | Placement, Area, Volume, Floor, Height, Orientation                |    |     |     |            |             |
| Landscaping per orientation considering seasonal solar gain and shading | EnergyPlus, eQUEST | Site       | Microclimate        | Shade by surroundings, Reflection by surroundings, Solar radiation modulated by surroundings, Ground reflectance modulated by surroundings, Air temperature elevation by urban heat island effect |    |     |     |            |             |
| Landscape                                                         | Tree                  | Type, Orientation |                      |                                                                      |    |     |     |            |             |
| Envelope finish considering solar absorption and reflectance       | EnergyPlus, eQUEST, TRNSYS | Roof       | G&T                 | Placement, Area                                                   |    |     |     |            |             |
|                                                                   |                       | Exterior finish | Color, Reflectance  |                                                                      |    |     |     |            |             |
| Window/Curtain wall/Sky light                                     | EnergyPlus, eQUEST, TRNSYS | Window/Curtain wall/Sky light | G&T                 | Placement, Area                                                   |    |     |     |            |             |
|                                                                   |                       | Glazing     | SHGC, VT            |                                                                      |    |     |     |            |             |
|                                                                   |                       | Frame/Mullion | Glass-Frame ratio  |                                                                      |    |     |     |            |             |
|                                                                   |                       | Shade       | Exterior horizontal/vertical shade |                                                    |    |     |     |            |             |
| Cool roof                                                         | EnergyPlus, eQUEST, TRNSYS | Roof       | G&T                 | Placement, Area                                                   |    |     |     |            |             |
|                                                                   |                       | Exterior finish | Color, Reflectance  |                                                                      |    |     |     |            |             |
| Glazing considering solar gain and shading                         | EnergyPlus, eQUEST, TRNSYS | Window/Curtain wall/Sky light | Glazing | U-value, SHGC, VT |                                      |    |     |     |            |             |
|                                                                   |                       | Frame/Mullion | U-value, Glass-Frame ratio, Air tightness |                                                    |    |     |     |            |             |
|                                                                   |                       | Shade       | Exterior horizontal/vertical shade |                                                    |    |     |     |            |             |
| Electrochromic Glazing                                            | EnergyPlus, eQUEST | Window/Curtain wall/Sky light | Glazing | SHGC, VT |                                      |    |     |     |            |             |
| Air-tight envelope to reduce infiltration                          | EnergyPlus, eQUEST, TRNSYS | Exterior wall | Construction | Air tightness |                                      |    |     |     |            |             |
|                                                                   | Door Vestibule        | Placement, Volume |                          |                                                                      |    |     |     |            |             |
|                                                                   | Window/Curtain wall/Sky light | Frame/Mullion | Air tightness |                                                          |    |     |     |            |             |
| Double skin facade/air flow window                                | EnergyPlus, TRNSYS | Window/Curtain wall/Sky light | Glazing | U-value, SHGC, VT |                                      |    |     |     |            |             |
|                                                                   | Exterior wall Frame/Mullion | U-value, Glass-Frame ratio, Air tightness |                      |                                                                      |    |     |     |            |             |
| Green roof                                                        | EnergyPlus, TRNSYS *not yet commercial | Roof | Construction | R-value, Heat capacity |                                                |    |     |     |            |             |
|                                                                   | Insulation            | Insulation, R-value |                          |                                                                      |    |     |     |            |             |
|                                                                   | Landscape Tree, Grass | Type, Orientation |                          |                                                                      |    |     |     |            |             |
| Green wall                                                        | TRNSYS                | Exterior wall | Construction | R-value, Heat capacity |                                                |    |     |     |            |             |
|                                                                   | Insulation            | R-value |                          |                                                                      |    |     |     |            |             |
|                                                                   | Landscape Grass | Type, Orientation |                          |                                                                      |    |     |     |            |             |
| Light shelf                                                       | EnergyPlus, Equest | G&T | Placement, Area |                                      |    |     |     |            |             |
|                                                                   | Glazing               | U-value, SHGC, VT |                          |                                                                      |    |     |     |            |             |
| Sky light                                                         | EnergyPlus, eQUEST, TRNSYS | Window/Sky light | Frame/Mullion | U-value, Glass-Frame ratio, Air tightness |                                              |    |     |     |            |             |
| Light duct                                                        | EnergyPlus            | Shade       | Exterior horizontal/vertical shade |                                                    |    |     |     |            |             |
| Category                          | Simulation | Object                                    | Sub-Object                                           | LOD Description                                                                 | PS | SD  | D  | CD  | Cons/Occup |
|----------------------------------|------------|-------------------------------------------|------------------------------------------------------|---------------------------------------------------------------------------------|----|-----|----|-----|-------------|
| Trombe wall                      | EnergyPlus, eQUEST, TRNSYS | Blind/Curtain                              | Indoor blind                                         | Placement, Area, Orientation                                                     |    |     |    |     |             |
|                                  |            | Exterior wall                              | Construction                                         | R-value, Heat capacity                                                            |    |     |    |     |             |
|                                  |            | Window/Curtain wall                        | Glazing                                              | U-value, SHGC                                                                  |    |     |    |     |             |
| EVB (Exterior Venetian Blinds)   | EnergyPlus, eQUEST, TRNSYS | Window/Curtain wall                        | Shade                                                | Exterior horizontal/vertical shade                                              |    |     |    |     |             |
| PCM (Phase Change Material)      | EnergyPlus, TRNSYS | Exterior wall                              | Construction                                         | R-value, Heat capacity, Air tightness                                           |    |     |    |     |             |
|                                  |            | Insulation                                | R-value                                              |                                                                                    |    |     |    |     |             |
|                                  |            | Ceiling                                   | Construction                                         | Color, Heat capacity                                                            |    |     |    |     |             |
| ECM                              |            | Simulation                                | Object/Sub-Object                                    | LOD                                                                              |    |     |    |     |             |
| High efficiency plant            |            | EnergyPlus, eQUEST, TRNSYS                | Heat exchanger for district heating                   | Placement, Capacity                                                             |    |     |    |     |             |
|                                  |            |                                          | Efficiency, Heat source type                         |                                                                                    |    |     |    |     |             |
|                                  |            | Water/Steam boiler                        | Placement, Heating capacity                          |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | Fuel type, Tube type, Efficiency                     |                                                                                    |    |     |    |     |             |
| High efficiency refrigerator     |            | EnergyPlus, eQUEST, TRNSYS                | Vapor compression chiller                             | Placement, Capacity                                                             |    |     |    |     |             |
|                                  |            |                                          | COP, Compression refrigeration type, Compressor type, IPLV, Performance curve, Compressor control |                                                                                    |    |     |    |     |             |
|                                  |            | Absorption chiller                        | Placement, Cooling capacity, Hot water capacity      |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | Heat source connection, Fuel for direct fire, External heat source, Cooling COP, Heating COP, IPLV, Performance curve |                                                                                    |    |     |    |     |             |
|                                  |            | Ice storage                               | Placement, Heat capacity                             |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | Volume, Ice making type, Insulation, Refrigerant type |                                                                                    |    |     |    |     |             |
|                                  |            | CHW storage                               | Placement, Heat capacity                             |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | Volume, Insulation                                   |                                                                                    |    |     |    |     |             |
| Variable speed compressor, condenser, pump, fan | EnergyPlus, eQUEST, TRNSYS | Heat pump/Variable Refrigerant Flow (VRF) | Compressor                                          | Speed control                                                                   |    |     |    |     |             |
|                                  |            |                                          | Fan                                                  | Flow control                                                                    |    |     |    |     |             |
|                                  |            |                                          | Vapor compression chiller                             | Compression refrigerator type, Compressor type, Compressor control               |    |     |    |     |             |
| Absorption chiller-heater        |            | EnergyPlus, eQUEST, TRNSYS                | Absorption chiller                                   | Placement, Cooling capacity, Hot water capacity                                  |    |     |    |     |             |
|                                  |            |                                          | Heat source connection, Fuel for direct fire, External heat source, Cooling COP, Heating COP, IPLV, Performance curve |                                                                                    |    |     |    |     |             |
| District heating and cooling     |            | EnergyPlus, eQUEST, TRNSYS                | Heat exchanger                                       | Placement, Capacity                                                             |    |     |    |     |             |
|                                  |            |                                          | Efficiency                                            |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | Heat source type                                      |                                                                                    |    |     |    |     |             |
| Optimal on/off for plants        |            | EnergyPlus, eQUEST, TRNSYS                | Water/Steam boiler                                   | HW reset, On-demand control                                                      |    |     |    |     |             |
| On-demand operation for plants   |            |                                          | Water/Steam boiler                                   | On-demand control                                                               |    |     |    |     |             |
| Outside air and load reset for CHW, CW, HW | EnergyPlus, eQUEST, TRNSYS | CHW, CW, HW Pump                                 | Placement                                            | Efficiency, Performance curve (Flow rate, Head)                                  |    |     |    |     |             |
|                                  |            |                                          | CHW, CW, HW Pipe                                     | Flow control                                                                    |    |     |    |     |             |
|                                  |            |                                          | Placement, Diameter, Length                          |                                                                                    |    |     |    |     |             |
|                                  |            |                                          | U-value, Inlet outlet water delta t, Pressure drop per unit length, Pressure drop by fitting, Pressure drop by plant, Pressure drop by equipment/device, Pressure drop by control and balancing |                                                                                    |    |     |    |     |             |
| Optimized HVAC zoning | EnergyPlus, eQUEST, TRNSYS | AHU | Placement, Volume, Cooling capacity, Heating capacity, Configuration, Dimension |  |  |
|-----------------------|-----------------------------|-----|---------------------------------------------------------------------------------|---|---|
| Heat pump/Variable Refrigerant Flow (VRF) | EnergyPlus, eQUEST, TRNSYS | Placement, Heating capacity, Cooling capacity, length, Configuration |  |  |
| ECM | Simulation | Object | LOD | Sub-Object | PS | SD | D | CD | Cons/Ocup |
| Dedicated Outdoor Air System (DOAS) | EnergyPlus, eQUEST, TRNSYS | AHU | Heat/enthalpy recovery | Type, Flow rate, Heating heat recovery rate, Cooling heat recovery rate |  |  |
| FCU | EnergyPlus, eQUEST, TRNSYS | Placement, Cooling capacity, Heating capacity, Air flow rate, HW flow rate, CHW flow rate |  |  |
| Chilled beam Diffuser | EnergyPlus, eQUEST, TRNSYS | Placement, Actuation type Induction ratio, Cooling capacity, Heating capacity, Air flow rate, HW flow rate, CHW flow rate Indoor unit control |  |  |
| Underfloor Air Distribution System, Displacement ventilation systems | EnergyPlus, eQUEST, TRNSYS | Placement, Actuation type Return air type |  |  |
| Zone | EnergyPlus, eQUEST, TRNSYS | Placement, Area, Volume |  |  |
| Mass | EnergyPlus, eQUEST, TRNSYS | Placement, Area, Volume, Height, Orientation |  |  |
| Heat/Enthalpy Recovery Ventilation | EnergyPlus, eQUEST, TRNSYS | AHU | Heat/enthalpy recovery | Type, Flow rate, Heating heat recovery rate, Cooling heat recovery rate |  |  |
| Desiccant and evaporate cooling | EnergyPlus, eQUEST, TRNSYS | DOAS | Desiccant Cooling | Desiccant type |  |  |
| Night purge control | EnergyPlus, eQUEST, TRNSYS | AHU | Night purge |  |  |
| Demand Controlled Ventilation (DCV) | EnergyPlus, eQUEST, TRNSYS | AHU | Economizer | OA control |  |  |
| Duty cycle control | EnergyPlus, eQUEST, TRNSYS | AHU | Duty cycle control |  |  |
| Optimal on/off control for AHU | EnergyPlus, eQUEST, TRNSYS | AHU | Economizer | OA control |  |  |
| Outside air temperature and load reset | EnergyPlus, eQUEST, TRNSYS | Boiler | HW reset |  |  |
| Garage Carbon Monoxide control | TRNSYS | AHU | CO control for garage |  |  |
| High efficiency water heater | EnergyPlus, eQUEST, TRNSYS | Water heater | Placement, Hot water capacity, Fuel type, Efficiency, Water storage |  |  |
| Insulated pipe | EnergyPlus, eQUEST, TRNSYS | CHW, CW, HW, DHW pipe | U-value |  |  |
| Water saving closet and tab | EnergyPlus, eQUEST, TRNSYS | Closet, Tab | Placement, Volume, Heat, Boiling method Insulation |  |  |
| Daylight sensor | EnergyPlus, eQUEST, TRNSYS | Ambient light | Light schedule, Daylight control, LED deeming control, Exterior light automatic on/off, Grouping control |  |  |
| Deeming and on/off control | EnergyPlus, eQUEST, TRNSYS | Ambient light | Light schedule, LED deeming control, Exterior light automatic on/off, Grouping control |  |  |
| ECM                          | Simulation         | Object                     | Sub-Object                  | LOD                        | PS | SD | D | CD | Cons/ Occup |
|------------------------------|--------------------|----------------------------|-----------------------------|----------------------------|----|----|---|----|--------------|
| Lighting schedule per space | EnergyPlus, eQUEST, TRNSYS | Ambient light              | Light schedule              |                            | ☐  | ☐  |   |    |              |
| Photovoltaic exterior light | EnergyPlus, eQUEST, TRNSYS | Ext. light                 | Placement, Wattage, On-site PV attached |                            | ☐  | ☐  |   |    |              |
|                             |                    | Solar panel                | Placement, Area, Azimuth, Angle, Seasonal shade |                            | ☐  | ☐  |   |    |              |
|                             |                    | Photovoltaic               | Module type, Tracking mode Generation capacity, Generation efficiency | Nominal operation cell temperature, Temperature coefficient, Loss coefficient | ☐ | ☐ |   |    |              |
|                             |                    | Inverter                   | Placement, Capacity         |                            | ☐  | ☐  |   |    |              |
| Parasitic load control      | EnergyPlus, eQUEST, TRNSYS | Static capacitor           | Placement, Voltage, Wattage, Current |                            | ☐  | ☐  |   |    |              |
| Sequence control, group and schedule management of elevator/escalator | EnergyPlus, eQUEST, TRNSYS | Elevator/ Escalator        | Placement, Number           |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Control                     |                            | ☐  | ☐  |   |    |              |
| Solar water and space heating | EnergyPlus, eQUEST, TRNSYS | Solar panel                | Placement, Area, Azimuth, Altitude, Seasonal shade |                            | ☐  | ☐  |   |    |              |
|                             |                    | Hot water tank             | Placement, Volume, Heat capacity |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Insulation                  |                            | ☐  | ☐  |   |    |              |
|                             |                    | Primary pump               | Placement, Power            |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Efficiency, Performance curve (Flow rate, Head) |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Flow control                |                            | ☐  | ☐  |   |    |              |
|                             |                    | Heat exchanger             | Placement, Capacity, Efficiency |                            | ☐  | ☐  |   |    |              |
| Solar air heater            | EnergyPlus, eQUEST, TRNSYS | Solar panel                | Placement, Area, Azimuth, Altitude, Seasonal shade |                            | ☐  | ☐  |   |    |              |
|                             |                    | Supply fan                 | Placement, Power            |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Revolving type              |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Efficiency, Performance curve (Flow rate, Pressure) |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Flow volume control (CAV, VAV) |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Variable flow control (RPM, Outlet/Inlet damper, Inlet vane, Variable pitch) |                            | ☐ | ☐ |   |    |              |
| Geothermal heat pump        | EnergyPlus, eQUEST, TRNSYS | Heat pump                  | Placement                   |                            | ☐  | ☐  |   |    |              |
|                             |                    |                           | Cooling capacity, Heating capacity, Cooling COP, Heating COP |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Compressor control          |                            | ☐  | ☐  |   |    |              |
|                             |                    | Ground heat exchanger      | Placement, Land area, Length, Number, Pipe diameter, Distance between pipes |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Type                        |                            | ☐  | ☐  |   |    |              |
| Geothermal heat pump        | EnergyPlus, eQUEST, TRNSYS | Primary and Secondary pump | Efficiency, Performance curve (Flow rate, Head) |                            | ☐ | ☐ |   |    |              |
|                             |                    |                           | Flow control                |                            | ☐  | ☐  |   |    |              |
| Expansion tank             | EnergyPlus, eQUEST, TRNSYS | Expansion tank            | Placement, Volume, Heat capacity |                            | ☐  | ☐  |   |    |              |
TABLE II: PHASES OF THE BUILDING DESIGN PROCESS

| Phase                        | Detailed tasks                                                                 |
|------------------------------|--------------------------------------------------------------------------------|
| Pre-Schematic Design (PS)    | Outline space plan, Check Building code, Field study, Analysis of existing building, User analysis |
| Schematic Design (SD)        | Rough estimation, Planning of building and MEP, Examine approval process         |
| Design Development (DD)      | Approval, Drawing layer                                                        |
| Construction Document (CD)   | Embody drawing, Create construction document, Estimating detailed construction expenses |
| Construction/Post occupancy  | Bidding, Construction, Operation                                                |

![Building energy consumption factors](image)

Fig. 2. Building energy consumption factors.

V. LEVEL OF DETAIL (LOD) OF AN ECM

First, we have investigated the design phases at which design elements and attributes of architectural and MEP objects are determined according to the building design process in Table III.

TABLE III: PRIMARY DESIGN ENTITIES DETERMINED IN EACH DESIGN PHASE

| Design phase               | Architecture          | MEP                                      |
|----------------------------|-----------------------|------------------------------------------|
| Pre-Schematic Design (PS)  | Mass plan, Standards for design | Placement, Type and area of Geothermal heat exchange |
| Schematic Design (SD)      | Building size, Zoning, Shape, Material | Schedule, Block planning of Renewable system |
| Design Development (DD)    | Detailed Property      | Placement, Type, Capacity, Efficiency, Control |
| Construction Document (CD) | Fixed                 | Fixed                                    |

In the pre-schematic design phase, layout and mass planning (such as location, orientation, height and area of a building) are mainly discussed with a feasibility study and then confirmed in the schematic design phase. Design criteria and conditions are already fixed (such as the surrounding terrain and climate of the building) before the design process begins. For MEP, it is very little to be determined at this stage because no specific design values are available yet. Since a ground heat exchanger is, however, installed in the site, the position and area of the geothermal system need to be considered together within the building layout. In the schematic design stage, an overall shape, structure and materials of a building (such as envelopes, story height, stairs) are determined. In the MEP, user schedule, lighting and ventilation can be captured considering the use and size of the building. In addition, properties such as location and area are discussed for design entities located outside the building such as solar panels or underground heat exchangers.

In the design development stage, as most design values related to the building is determined, properties of MEP are started to be determined. At the beginning of this phase, placement, type and capacity of the equipment are settled down and properties related to the building controls are determined in the latter part of this stage.

In the construction document phase, most properties are determined and there can be necessary design changes. In Table I, the design phase at which each ECM is discussed is marked by □, and the design phase at which it is confirmed is indicated by ■.

VI. SIMULATION PROGRAMS FOR EVALUATING BUILDING ENERGY PERFORMANCE

Building energy simulation has been developed since 1970, and a use of simulation tools has been highly encouraged for green building designs. However, contrary to the advocacy group who goes for a new technology of building simulation, the pragmatist groups such as design engineers are somehow reluctant to understand unfamiliar simulations.

Therefore, in this paper, we have tried to propose a guideline of simulation use in order to encourage the simulation practitioners in easily evaluating the building energy performance. We have investigated a functionality of DOE-2.1, ECOTECT, EnergyPlus, eQUEST, ESP-r, HAP, IDA ICE, IES <VE>, Tas, TRACE and TRNSYS to determine what simulation tools best capture ECMs at each design stage. But only EnergyPlus, eQUEST and TRNSYS are marked in Table I, because they are mostly used simulations in Korea.

VII. CONCLUSION

To encourage energy simulations in building design, this paper proposes a guideline concerning what simulation is appropriate for each ECM to practitioner designers who are lack of the expertise in energy simulation. We hope to convince the people who have a sense of discomfort with unfamiliar simulations, such that various applications of building energy simulation can be tried out in the design phase. We also expect a convergence between architectural designers who is lack of the expertise of equipment, and MEP designers who is lack of the expertise of architecture. Therefore a systematic and integrated design can be implemented from the initial planning phase to the operation and maintenance phase.

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Mina Choi will receive a B.S degree in engineering in February 2017 from the School of Architecture of Seoul National University of Science and Technology, Seoul, South Korea.

Gahee Kim will receive a B.S degree in engineering in February 2017 from the School of Architecture of Seoul National University of Science and Technology, Seoul, South Korea.

Sean Hay Kim received a Ph.D. from the Georgia Tech. Before joining the Seoul National University of Science and Technology, she worked for Siemens and Autodesk in the U.S.