COLLABORATIVE ENGINEERING: AN APPROACH TO MODERN CURTAINWALL DEVELOPMENT

MATTHEW COHN, E.I.T.

Architects are always pushing the envelope to develop the next great building. As technology progresses, architectural concepts grow in complexity. What may have started as an abstract form drawing on the back of a napkin becomes subject to stringent building codes, energy requirements, and constructability. But of course, no project can be realized without the money to actually build it. Often times this results in designers adapting their original architectural vision into systems more affordable and constructible. Today's architects rely on teams of consultants to help them through the development of their concepts. This also provides a means to roughly estimate a project's budget and develop a reasonable design solution. However, once the project is turned over to the general contractor, and eventually to specialized subcontractors, more detailed design and pricing is completed. Especially with complex projects, preliminary curtainwall budgets can be grossly underestimated, causing sacrifices later in design. By collaboratively developing design requirements, architects and curtainwall contractors should be able to jointly develop the architectural vision within the project constraints.

This paper proposes a collaborative engineering (CE) approach to curtainwall development. Often, collaborative engineering is confused with concurrent engineering. It is important to understand that in concurrent engineering, engineers work independently (sometimes opposite of one another) toward a common goal. Collaborative engineering requires that the engineers work together. Each member of the team must be a stakeholder who is fully vested in the outcome of the design process. Each one must contribute and bring an area of expertise that will fully benefit the team. A more detailed definition of collaborative engineering can be found in the Defining Collaborative Engineering section of this paper.

A collaborative approach to curtainwall development will ensure that proper stakeholders are involved in the appropriate process of the design. It will shorten the total product development timeline while increasing the quality of the product and reducing life-cycle costs. By utilizing collaborative engineering, a new iterative process for conceptual design will be proposed. Collaborative engineering will also allow for more innovative designs to be developed and realized.

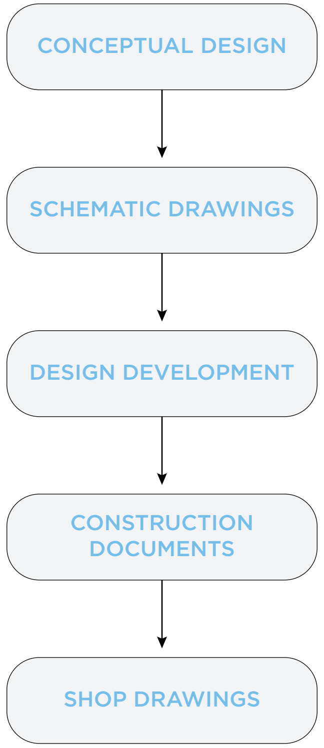
TYPICAL PRACTICE OF CURTAINWALL DESIGN

TYPICAL BUILDING DEVELOPMENT

The typical practice of building development can be described by the design flow diagram and figure opposite. First, an owner has a need for a new building. The owner approaches architecture firms to develop the building concept. Architects create preliminary concepts from which the owner can select. Once the owner has selected a specific concept, the architect begins to assemble the design team, and the design flow begins. Each arrow in the flow represents a review point where owner approval is required to move to the next phase. The design team consists of four major consulting groups: structural, mechanical, electrical and enclosure. It is the job of the consultants to help develop the architectural design so that each building component being developed will meet all the required codes while staying within budget and retaining constructability. Each consultant is an expert in their respective discipline.

As the design progresses, the architect begins interviewing general contractors—this typically occurs when the design is around 75% mature, but it has been trending earlier recently. The owner will then select a general contractor to lead the construction team with input from the architect. The general contractor will then begin assembling the construction team, consisting of four major subcontracting groups: structural, mechanical, electrical and curtainwall. These disciplines align with the design team consultants. When the construction manager solicits individual contractors, they are typically asking for a contractual commitment that includes cost, schedule and design feasibility. It is at this point that the architectural drawings begin to be developed and designed for production.

TYPICAL BUILDING DEVELOPMENT



As the construction team is assembled, the design process begins to shift from conceptual and schematic drawings to design development. Some requirements are levied by the design team that may or may not be possible. At this point, cost and constructability become a major factor. There is a link between the design and construction teams, but ultimately conflicting decisions are settled by the owner. The architect owns the design, but the general contractor owns the construction.

CONFLICTING INTERESTS

Although both the construction and design teams are working toward a common goal, many of their interests can conflict. For instance, at a fundamental level, the design team is more concerned with the architectural expression of the building, while the construction team is more concerned with cost and constructability. This can create issues where either the design must be compromised or the cost goes up as a result of decisions made. The owner acts as a single decision point to settle any conflicting issues.

There is also the conflict of money. When different organizations must work together on a common project, each individual organization must ensure that they remain profitable in order to survive. The owner obviously wants to minimize cost, but contractors must turn a profit. This can create cost conflicts that could compromise the design or schedule.

The linear process of design can create conflicts between different phases of development. There can be major discontinuities in the different phases of design and production. For instance, gaps in the conceptual and detailed design phases can cause the optimized design to be greatly compromised. Once the conceptual design is finished, there is no returning to it. If changes must be made, the original design is compromised. Another more visible example is frequently seen in the gap between design and production. Many components that are obvious to the design engineer may not be clear to the production engineer. Specifications may be under-defined or impossible to fabricate. Also, many components may be changed or misrepresented by different phases in the process.

TYPTICAL DESIGN-CONSTRUCTION INTERACTIONS

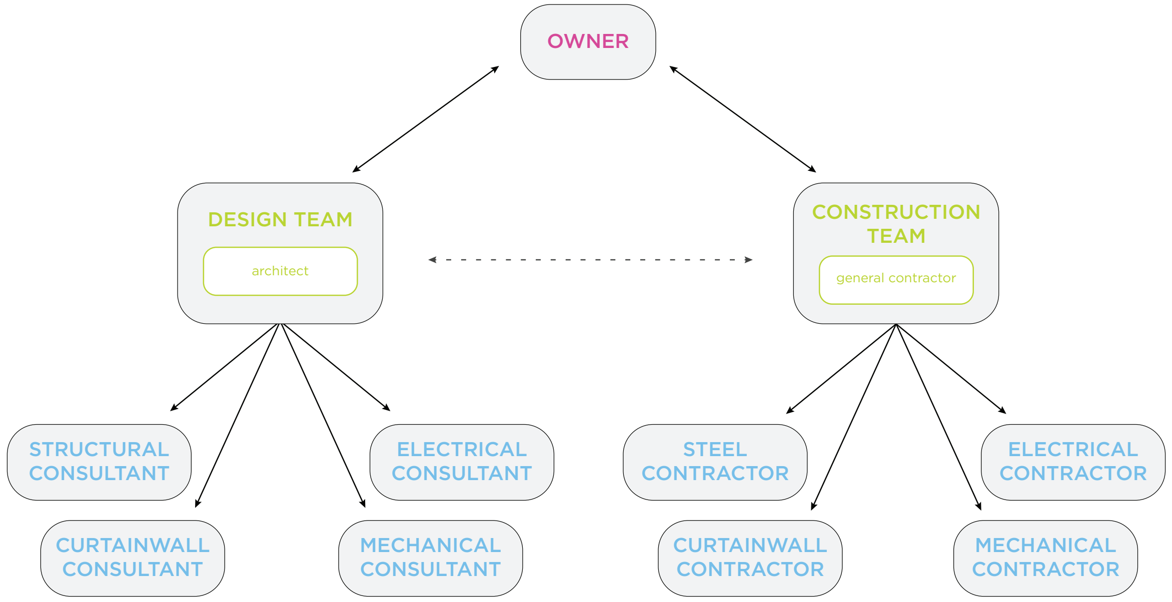


FIGURE 1
A typical building development workflow.

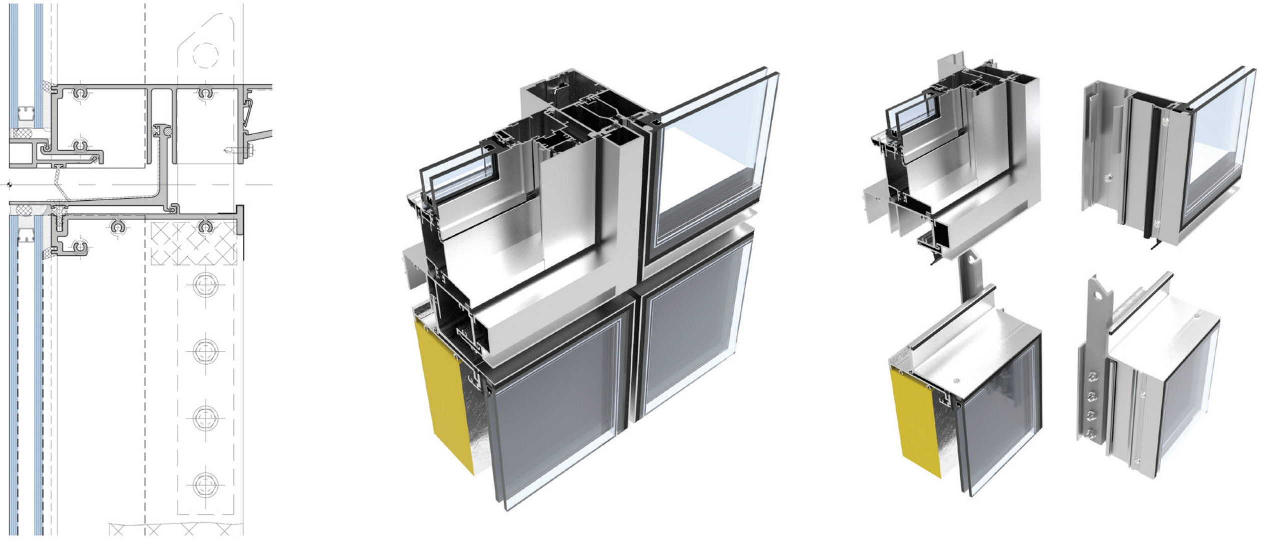
FIGURE 2
Typical interactions during the design/construction process.

These problems can be minimized with the collaborative engineering process. Production stakeholders will be involved throughout the design process, ensuring a smooth transition from design to production. By including production engineering stakeholders early in the process, production issues will be anticipated and addressed as they arise. Also, by correctly enforcing these collaborative principles, compromises to earlier designs become unnecessary. This is achieved because each iteration of the design phase will not have an optimized design, but rather a "sufficing" design.

CONSULTANTS VS. CONTRACTORS

The architects' consultants serve an important role, acting as advisors throughout the entire design and production process. This helps architects create realistic designs that conform to codes and remain constructible. Also, as contractors are assigned and detailed drawings begin to emerge, the consultants act as a check to the contractor—ensuring they conform to the specification, don't cut corners, and comply with the overall design intent.

While consultants act as advisors to the architect, ultimately the contractor assumes liability for the finished product. This means that they must fully design the system and get all drawings and calculations certified. Often times, design changes are necessary in order to create something that will work for all possible conditions. Generally, during the early design phases, there simply isn't enough time for consultants to



completely flush all design issues. They tend to focus on larger details to ensure overall feasibility of the project. This is even more evident as projects become increasingly complex. Some design issues simply cannot be discovered until a project is deep into detailed design. This can result in “sticker shock” for the owner and architects as contractor bids come in. During the bid process, contractors must attempt to flush out as many design issues as possible to put an accurate number to the cost of the job. If the owners have created budgets on unrealistic expectations, this can have a serious impact to the future of the project.

DEFINING COLLABORATIVE ENGINEERING

OVERVIEW DEFINITION

Collaborative engineering is a process of multidisciplinary stakeholders working together to develop a common product, outcome or goal. The stakeholders may be of differing backgrounds with conflicting interests, yet a common objective must be achieved. The interaction between varying stakeholders makes collaborative engineering both a social and technical decision problem in which technical task-work must be synchronized with social teamwork. Therefore, collaborative engineering is bound by social decision theory.[1] The framework developed in this paper will divide the collaborative process into two multi-attribute decision problems that must be solved simultaneously in order to achieve a rational decision. The first problem is an MSC problem and the second is an MCE problem.

Since both major problems in collaborative engineering follow the same multi-attribute decision structure, they are both bound by limitations of social decision theory.[1] Engineering problems are typically not considered as existing within social theory, but there is no avoiding it in collaborative engineering. One of the more interesting (and most challenged) social theories is Arrow’s Impossibility Theorem.

^
FIGURE 3
Multiple representations of a stack joint, including a two-dimensional section (left), a three-dimensional rendering of an assembled stack joint (center), and an exploded view of the rendering showing internal connections (right).

Essentially this theory states that it is impossible for a group to make a rational group decision if the group has the following attributes: democracy, independent alternatives, consistency, and an unrestricted domain.[2] On the surface, this suggests that there is no way to collaboratively fulfill a problem’s requirements; however, there is hope for collaborative engineering. Arrow’s theory only holds true if all four limitations are met, but engineering problems never exist in an unrestricted domain. There are always limitations that restrict the domain of available alternatives (solutions) — cost, schedule, regulations, etc. By restricting the domain to reasonable alternatives, it becomes possible to make a sound, rational collaborative engineering decision.[2]

It is important to note that collaborative engineering is a social theory problem, and that it is possible to make a rational decision in a group setting. Since the collaborative teams contain stakeholders with the conflicting interests described under Conflicting Interests in Typical Practice of Curtainwall Design, we need to draw on social theory to help manage the social interactions. It is also important that we understand that the only thing that makes a rational group decision possible is the restricted domain. If collaborative teams get too caught up in examining every possible alternative, the process cannot succeed.

As stated earlier, this paper divides the collaborative engineering framework into two major problems: Multi-Stakeholder Choice and Multi-Criteria Evaluation. MSC problems represent teamwork, while MCE problems address task-work. However, these two problems rely on the organization for the problem definition and the stakeholder assembly. The organization must set an assignment or high-level goal for the collaborative engineering team. Then they must assemble a team of stakeholders to address the problem. A stakeholder is anyone who has a vested interest in the outcome of the product being developed. Among others, this includes several different types of engineers with different specializations, managers, marketers, customers, and any other person that has an interest in the developmental outcome, and a useful expertise. After the organization has a clear assignment and a collection of stakeholders, the collaborative process can begin.

MULTI-STAKEHOLDER CHOICE PROBLEM

The MSC problem begins after the assembly of the team members. This is the process of systematically managing social interactions — teamwork. This is where collaborative engineering is very different from the traditional approach to an engineering problem: it is a value-focused thinking process.[3] In traditional engineering problems, engineers are given specific objectives that must be met. In the value-focused approach, it is up to the collaborative team to identify decision opportunities in order to define their own set of objectives. This allows engineers to explore more opportunities allowing for a greater level of innovation. Identifying a decision opportunity is essentially the team working together to determine areas where they can focus their work.

The team of stakeholders must first interact to develop a common understanding of the project/problem. Stakeholders will have different values and perspectives that coincide with their backgrounds and specific expertise. They must influence each others' perspectives in order to acquire a shared understanding of the task at hand. There is an opportunity for the social and technical diversity of the group to work positively for the team.

The interactions of the MSC problem must be systematically managed in order to clearly identify decision opportunities. For this to happen, there must be a clear input, a defined process, and an observable output. In this case, the input is the group of stakeholders and the defined assignment or high-level goal. The stakeholders must identify their differing perspectives toward the issue and begin to create propositions or possibilities to solving the problem. Basically, this is an attempt to assess what is more important to the group and to what degree something is preferred — i.e.,“this is three times more important than that”. By restricting the domain to only viable alternatives, weighted ranking becomes possible.[2] Note that if for some reason a collective rationality cannot be reached, the entire process must be repeated until the team can align their perspectives with the goal and achieve a rational set of objectives that are agreed upon by all stakeholders.

When a collective rationality is achieved, the teamwork (MSC) portion of collaborative engineering is nearly complete. The team must now create a set of objectives that corresponds to the different alternatives and a set of criteria to evaluate their progress. The stakeholders must set their objectives to align with the overarching goal and their own personal expertise. The team must also develop evaluation criteria. Otherwise, any attempt to evaluate the overall utility of the team’s different alternatives is useless. After the team has set clearly defined objectives and evaluation criteria, the MSC portion of collaborative engineering is complete.

MULTI-CRITERIA EVALUATION PROBLEM

The second phase of collaborative engineering is the MCE problem, also referred to as multi-objective optimization. This problem is the traditional approach to engineering problems. However, by defining it in terms of collaborative engineering, we are able to create a more systematic approach to solving complex problems. Also, by creating the objectives and evaluation criteria collaboratively, the MCE problem gives more opportunity for both more practical and more innovative designs.

MCE defines the task-work portion of collaborative engineering. The purpose is to complete the individual tasks under the context of the common understanding developed in the previous stage. The inputs for the MCE problem are the objectives and evaluation criteria developed in the MSC problem. The output of this stage should be viable alternatives (or multiple solutions) that are used to attain a final agreement. Essentially, once you have collaboratively developed the goals and objectives of the problem, you can assign the tasks to develop solutions.

Here, the individual stakeholders will use their expertise to complete individual objectives that were developed in the MSC stage. The team must dynamically collaborate both during their said technical task-work and after its completion. Since a shared understanding was developed in the previous stage, each stakeholder – although they may have vastly different perspectives – has a clear understanding of what the team wants to accomplish. The team will progress from individual perspectives to a set of well-developed alternatives (e.g., multiple possible solutions). The team may then be able to employ multi-objective optimization to find the best possible solution. This will result in a participative joint decision, representing the end of the collaborative engineering process. However, in many cases multi-objective optimization is not possible. The team can either repeat the MCE process until a group rationality is reached, or they can engage in collaborative negotiations to attain a sufficing solution. In either process, there are clear evaluation criteria (developed in the previous stage) that can be used to judge the overall utility of different alternatives. The output of this stage is a group rationality that results in a team agreement (i.e., a valid solution to the collaborative engineering problem).

Although optimization techniques can be used, this does not necessarily represent the "optimal" solution. It represents a sufficing solution based on the evaluation criteria developed in the first MSC stage. This does not mean it is a sub-par solution. Rather, it is the best realistic solution for your collaborative engineering group, based on the needs of your organization and the perspectives of the selected stakeholders. This does, however, represent the best, most complete solution for the particular team, based on limited resources and conflicting interests that are seen in nearly all modern-day engineering endeavors. The following sections will show how this collaborative process can be applied to the problem of curtainwall design, and how it will improve developmental efficiency and innovative capacity.

A COLLABORATIVE APPROACH TO CURTAINWALL DESIGN

The specific framework above provides a method to help increase the efficiency of curtainwall development while simultaneously providing an opportunity to increase innovation. This section will show how the specific steps and tasks necessary in curtainwall development can progress within the collaborative framework.

CONCEPT SELECTION & OVERARCHING REQUIREMENTS

For the purpose of this paper, we will assume that the overarching building type and requirements have already been set, and an architectural concept has been agreed upon. This is to say that the owner has already done his or her market research and determined the overall function of the prospective building (e.g., develop a high rise residential building to be built on a lot 'x' in New York City), and he or she has chosen an architect and concept. Ideally, these overarching requirements would be developed collaboratively with the curtainwall contractor, but this rarely happens in the architectural industry.

With a concept established and general requirements set, the collaborative process can begin. It is important to get the curtainwall contractor involved as early as possible. Traditionally, the curtainwall contractor is not involved until the architectural concept is about 75% complete. While the collaborative process can still proceed in this case, earlier is preferred. Essentially, the key is that the architect must be open to fully collaborating with the curtainwall contractor – the less unmovable design decisions, the better.

GOAL DEFINITION & STAKEHOLDER IDENTIFICATION

The first step of the process is to collaboratively define the objectives and evaluation criteria using the MSC approach. The owner is still ultimately responsible for the project, so he or she has the responsibility of identifying and assembling the stakeholders. For typical curtainwall development, a possible list of stakeholders is shown in Table 1. Among others, the stakeholders include the owner and representatives of the design and construction teams, as well as the curtainwall contractor and its associated experts. Notice that this is a full list of experts in all the different disciplines that affect curtainwall, as well as representatives from higher level clients. Their expertise and perspectives are also shown in the table above.

The table shows the diversity of the stakeholders and their complementary expertise, showing that they bring a certain perspective to curtainwall development that is vital to the design process. All of the stakeholders have the same goal of developing a curtainwall system that meets the overarching requirements and fulfills the owner's and architect's vision for the building. However, the differing perspectives can create conflicting interests. The team must identify the members' differing perspectives in order to better understand where specific expertise lie and the reasons for their perspectives. Although there may be conflicting interests, by assembling a team that consists of experts in all fields related to curtainwall, the team's varying perspectives can help eliminate costly changes later in the design and production processes. For example, if this team was assembled without an acoustical engineer, the structural and thermal engineers might size the glass perfectly well to meet the requirements from their perspective, but a different glass makeup might be required to meet all acoustical requirements. By having an acoustics engineer as part of the initial team, these concerns are addressed up front, eliminating a possible redesign of the system structure later to accommodate thicker and heavier glass.

STAKEHOLDER	EXPERTISE	PERSPECTIVE
Owner Representative	owner needs / limitations	budget and overall project completion
Architect	architecture and overall building design	most innovative / creative expression of the project
General Contractor	managing entire project construction	cost & schedule conscious
Consultant	overall curtainwall design and requirements	architect's vision 1st priority
Curtainwall Designer	curtainwall design and construction	design and cost / schedule efficiency
Curtainwall Structural Engineer	curtainwall structural engineering expert	system complies with structural codes
Building Structural Engineer	building structural engineer expert / in-depth knowledge of project building structure	curtainwall loads to structure
Curtainwall Thermal Engineer	thermal engineering expert	building conforms to thermal / energy requirements
Building Mechanical Engineer	building mechanical systems expert / in-depth knowledge of project mechanical systems	ensure adequate mechanical system capability
Acoustics Engineer	acoustic engineering expert	ensure building meets acoustical requirements

TABLE 1
Sample curtainwall design stakeholders.

Additionally, in the traditional approach, a curtainwall contractor may receive architectural drawings with a bid date and no further direction. The contractor is then left to examine the drawings himself, which could lead to misinterpretation of the architect's vision. The contractor may make an assumption to try to make their bid more competitive, but that decision might compromise their chances of selection due to a deviation from the architectural intent. Ensuring all stakeholders are present early on is an advantage for all parties. There should remain varying perspectives throughout the entire collaborative process. The next section will show how to manage these varying perspectives in a systematic approach.

MANAGE SOCIAL INTERACTIONS

Now that the team is assembled, specific goals and objectives for this stage must be determined using the MSC problem. As described previously in Defining Collaborative Engineering, this is clearly a problem of social interaction, bound by social theory. What often makes this problem difficult is that there are independent organizations with differing priorities that must work together toward a common goal. Each organization must retain profit margin while working within a finite budget. However, there is no secret to this concern. As long as all the stakeholders understand that conflicting interests exist and address them up front, the collaborative process can proceed.

Here, stakeholders will identify their personal perspectives toward the issue in order to develop propositions for possible solutions. As propositions are discussed socially within the team, different decision opportunities arise. When developing a curtainwall concept, these opportunities can include: mullion depth, glass makeup, installation process, sight lines, etc. It is very important at this stage that the stakeholders identify as many decision opportunities as possible since these will be inputs for design process that will be employed in the MCE stage.

Early in the process, the team will look at the project as a whole and look for particular areas of concentration. For instance, there may be a large atrium area that requires vision glass spanning three floors. The architects may want this area to be as transparent as possible (i.e., minimal structural support). In this situation, the architects likely have been advised by their consultants and have a solution that could work. However, now that the curtainwall contractor is involved, they can begin to offer different alternatives that may enhance the architect's vision while actually lowering the overall cost of that portion of the project. Having all the stakeholders present at this early stage allows there to be functional discourse between parties of different perspectives. It opens the door for innovative solutions to problems that may not have been fully vetted in the early conceptual phases.

In this situation it is easy to see how the team can get caught up in focusing on the more complex areas of the project. However, they must be careful not to forget the decision opportunities that lie in the more typical portions of the job. Mullions may have been sized conservatively early in concept development. There may be opportunities to adjust the mullion depth to improve efficiency and reduce metal in typical curtainwall areas. This might be something that the contractor could see as a chance to reduce project cost. However, if the architect is looking for a specific profile depth for whatever reason, the team should be aware. By assembling all the stakeholders in this way, the team can understand if and where decision opportunities exist.

Once the team has identified as many decision opportunities as possible, the MSC stage can move to objective formation. From the examples given previously, one objective may be to determine the optimum mullion profile for the typical curtainwall. Another might be to determine alternative solutions for the atrium. Here it is important to create measurable criteria that set parameters that the curtainwall contractor can use to bound the design problem. In the mullion example above, the problem may be bound by a maximum mullion depth set by the architect. This is a very specific and extremely important process where the team sets the specific goals of the task-work. The process differs from the traditional approach in that objectives are developed collaboratively instead of in isolation by the contractor. This will eliminate problems that can arise when the contractor makes assumptions about the design that might be unacceptable to the architect. In the collaborative approach, the contractor will still completely develop the design independently, while the goals, objectives and design parameters will have been developed collaboratively.

After developing objectives for the next stage, the team must develop evaluation criteria. Again this is done differently for each different design team. They must form criteria that will allow them to measure the overall utility of different design solutions, for use in the MCE problem. Once the team has clearly defined objectives and evaluation criteria, the collaborative engineering process can progress to the MCE stage. Aluminum weight versus mullion depth and width could be the measurable criteria for the mullion example above. This is a simple example, but it shows how criteria can be developed to determine the utility of an alternative.

In the MSC problem, the team will also develop a schedule that limits when certain alternatives must be presented for approval. This might be simply setting a meeting two weeks out with the anticipation of making a final decision on the mullion profile for the typical curtainwall conditions. The next section shows how the team can begin to develop alternatives/solutions.

DEVELOP ALTERNATIVES

The previous section fully developed the decision opportunities for the collaborative team to have the best possible opportunity to create an innovative, practical and well designed product. By assembling a team of vested stakeholders, the team was able to develop a rational set of decision opportunities from an understanding of project limitations. Staying with this example, the team now has a clear and quantitative understanding of the importance of different parameters for the curtainwall design (e.g., a thinner mullion profile is three times more important than the depth of the profile). Also, the team fully understands the objectives and how the task-work (MCE) phase will progress.

Stakeholders should now begin their individual task-work by completing the objectives set forth in the MSC phase. Ideally, all the task work would be completed collaboratively, but this is impossible when working with different organizations. However, since all of the objective criteria were developed collaboratively, the individual organizations can complete their task-work with a solid understanding of perspectives of all interested parties.

As discussed further in The Enclos Approach, Enclos has set up its design teams with a diverse set of designers and engineers to help the task-work progress as collaboratively as possible. This helps ensure that as many stakeholders as possible are applying their personal preferences to their task-work under the context of the team's collective rationality. Again we return to the mullion optimization example. The curtainwall designer would be developing details to make the system water-tight, manufacturable, etc. However, the curtainwall designer wouldn't be designing in a vacuum alone. The designer would have a structural engineer to give minimum design parameters, such as silicone bite required and minimum profile moments of inertia. The designer would also have a thermal engineer to assess the shapes for condensation and identify possible thermal paths. As individual preferences are applied to the task-work collaboratively, the team will begin to form a global rationality as their objectives near completion.

This approach allows design evolution to work to its best potential. Although not all stakeholders were present during the actual task-work completion, they collectively determined the objective and scheduled further collaborative sessions to assess alternatives. The team clearly understands the inputs to the design process, because they were formed using the collective rationality that the team agreed upon collaboratively in the MSC stage. Unlike the traditional approach, this framework allows for a clear understanding of the inputs, process and outputs of the curtainwall design process by all stakeholders. It also allows for a design and a design process that is specifically tailored to the specific project in work.

Although this design process is performed in a much more systematic manner, it does not guarantee that the output will be sufficient for every stage in the design. In fact, in the earlier iterations, the collaborative engineering team must develop several different alternatives with different configurations and varying emphases on the most important performance parameters. This will help develop several solutions or alternatives that can be examined in later iterations. Once the team completes their task-work for a specific schedule period, they will have several alternatives to evaluate further. At this point they will employ "multi-objective optimization" to determine overall utility of each alternative, based on the evaluation criteria developed in the MSC stage. The team will now aggregate their individual preferences and perspectives to determine their group preference.

NEGOTIATE JOINT DECISIONS

There are four possibilities at the end of the collaborative engineering process:

1. A participative joint decision
   (most desired)
2. Return to the beginning of the task-work (MCE) phase
3. Return to the beginning of the teamwork (MSC) phase
   (restart the entire CE process)
4. Negotiate a joint decision
   (results in sufficing group rationality — most common)

In earlier iterations, it may be relatively easy to attain a participative joint decision, because the team is selecting several successful alternatives to be developed further. However, as the number of iterations increases, the team must narrow design alternatives until they ultimately have a final design to move on to shop drawings. In the later iterations, it may be necessary to engage in collaborative negotiations or even repeat some of the stages. The ultimate goal is to attain group rationality, resulting in the best sufficing design.

Since the objectives were developed collaboratively, none of the solution alternatives should be unacceptable; however, some may be more preferable than others. Each iteration of collaborative engineering will refine the overarching goal, narrowing the design alternatives and forcing the CE team to create a more and more detailed design. There is always the opportunity for the owner or architect to reject one of the solutions of a previous iteration, but this will detract from the benefit of the collaborative process. Instead of systematically determining which alternative best satisfies the problem, this will have eliminated an alternative that may have produced an innovative result if developed further. In the early iterations, there should be a small, select group of experts that will create multiple, relatively generalized solutions. As the iterations progress, the stakeholders with more specific expertise will be selected to help refine the overall design. Eventually, the collaborative team will arrive at a single design solution that satisfies all requirements while considering its impact on further design and production phases.

ADVANTAGES OF COLLABORATIVE ENGINEERING

A collaborative engineering approach to curtainwall development will improve the current practice in several major ways, including:

1. The architect does not always rely upon a curtainwall consultant to fully solve the design problem. In the collaborative approach, the problem definition is developed collaboratively, ensuring that all major stakeholders can express their perspectives toward the architectural concept. This ensures that there is an in-depth consideration given to all aspects of the curtainwall design.

2. Stakeholders expose design engineers to different levels of the developmental process, allowing the early design solutions to include considerations from all levels of production. Ultimately, this creates more synergy throughout the developmental process, creating a more streamlined process (e.g., production and installation issues considered during the design phase).

3. Allowing representatives of the owner and general contractor to be involved in the design phase. Inclusion allows these parties to be more informed when handling the coordination and cooperation networks required during detailed design and production phases.

4. Streamline the transition from concept to production. Successive iterations can be employed to refine concepts until the design is fully defined, allowing a smooth progression into component development and shop drawings.

5. Fully defining objectives and understanding the inputs and process of design development. Additionally, the design process will be tailored to the specific problem.

6. By allowing several solutions to be developed in earlier iterations, there is a stronger possibility for innovative designs.

THE ENCLOS APPROACH

The Studios were created to keep Enclos at the forefront of curtainwall development as projects grow in scope and complexity. The Studios contain a diverse group of expertise that help the design team respond to these increasingly complex projects. Each Studio employs several senior designers that bring in-depth knowledge of curtainwall design along with a great deal of experience in past projects. There are many young architectural and industrial designers that bring new perspectives and expert knowledge in advanced architectural software. Each Studio also has devoted structural and thermal engineers, as well as engineering expertise in acoustics. This team is set up to respond to future proposals as well as engage in continuing research to advance the curtainwall industry.

The Studios are set up to engage in a collaborative approach to curtainwall design and development. Designers are not working in a linear fashion, waiting for their designs to be reviewed by engineering. The entire team can engage in collaboration throughout the design development phase. Although it may take time for the architectural industry to fully embrace a collaborative approach, the Studios can work in collaboration together to solve challenges that may arise.

Working within the framework of current industry practice, Enclos will often propose a design-assist phase with the Studios' bid package. The job is sold with the understanding that many of the unique, complex design features are less than fully matured. Design-assist is a method to collaboratively develop these design features and mitigate some of the potential risk to project completion. The intent of design-assist is to engage in full collaboration with the owner, architect, general contractor and curtainwall contractor. This is a great opportunity to employ the collaborative process described in this paper. By approaching the design-assist phase systematically, Enclos is able to realize complex and exciting new projects.

CONCLUSION

The collaborative engineering approach to curtainwall development has several key advantages to traditional methods. While many of the examples presented in this chapter represent simple scenarios, the process can be applied to a problem of any complexity. In fact, the more complex a project becomes, the more essential the collaboration. It is easy to become focused on your particular area of expertise when looking at a complex problem, but the collaborative engineering process allows you to consider other perspectives. Ultimately, organizations have more opportunity to create more innovative, more practical, and more financially sensible products and product cycles.