COMSOL® Application Builder Lets End-Users Harness the Power of Numerical Modeling and Simulation

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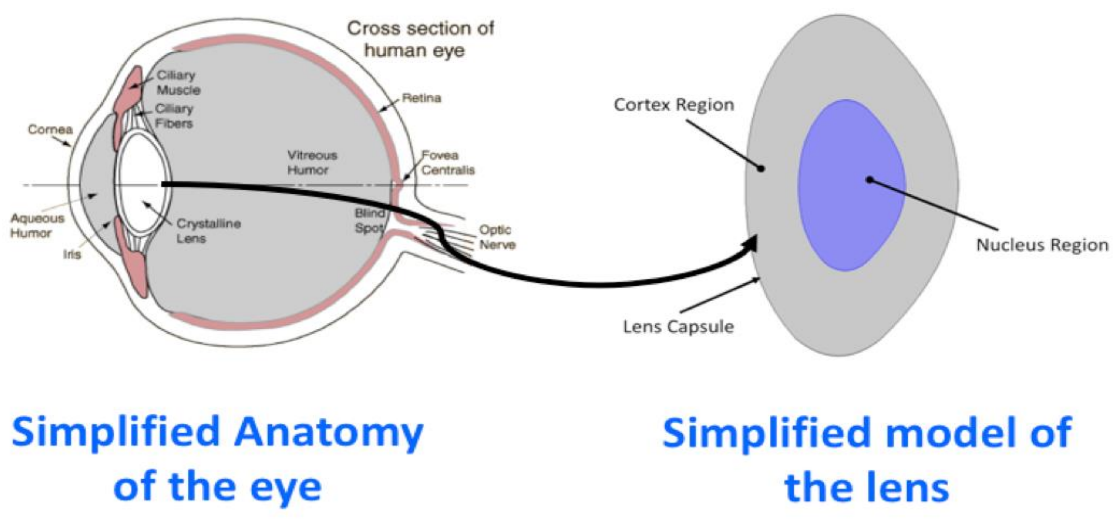
Introduction:

Kejako SA is an ophthalmology company focused on developing new innovative solutions to combat Presbyopia, a commonly occurring age-related eye condition. Presbyopia is when your eyes gradually lose the ability to see things up close clearly. It is a normal part of aging, which effects the material properties of the crystalline lens of the eye.



When we are young, the crystalline lens of the eye is soft and flexible, but as we age, it becomes stiffer as a result of aging effects of the cellular tissues which make up the lens.

Figure 1. Simplified Eye and Lens Schematic [1][2]

Kejako is proposing an innovative and non-invasive solution to address the root cause of the problem using a spatially targeted laser treatment to alter the optical and mechanical properties of the lens and restore mechanical flexibility and overall optical power. The goal of Kejako's numerical proof of concept work, is to characterize the effect of their proposed treatment. This requires a suitable quantitative method of measuring and determining the shear modulus of the lens pre and post to treatment. One such method involves the use of a test fixture (a.k.a. Lens Spinner) and COMSOL Multiphysics® to reverse engineer the shear modulus value from lens spinning test data.

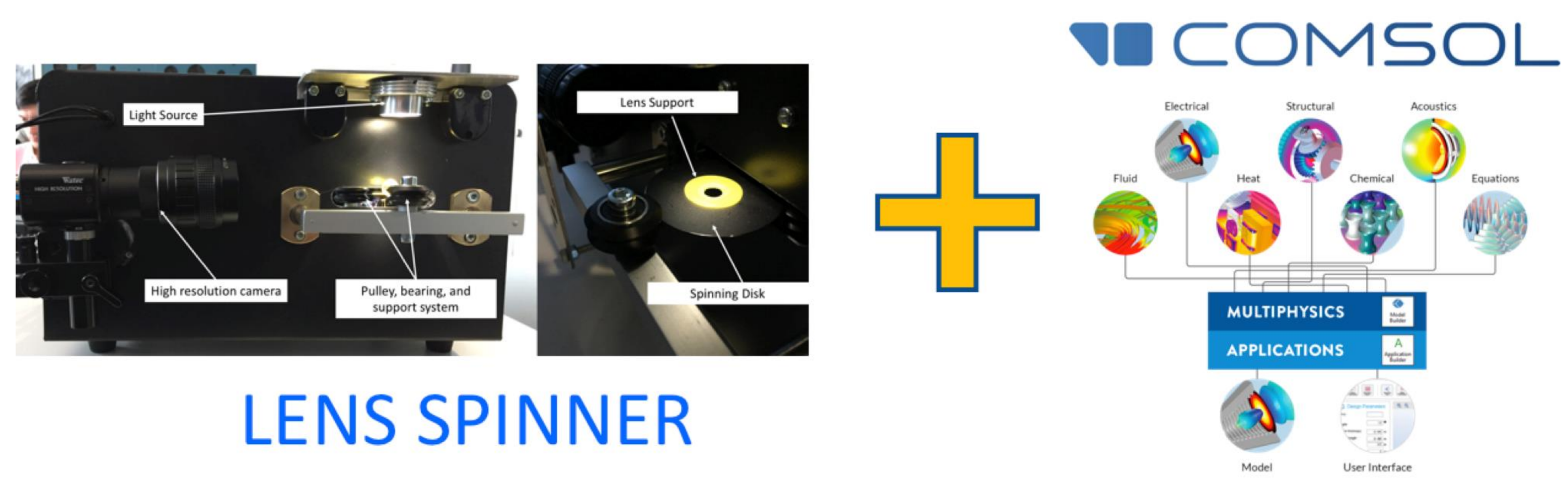


Figure 2. Lens Spinner [2] and COMSOL Multiphysics® [3]

The lens spinner is used to spin the lens at a specified rotational speed, which deforms the lens as a result of centrifugal force. This testing method is non destructive, as well as mimics the in-vivo forces that induce lens deformation during the visual accommodation process. COMSOL® is used to preform an inverse simulation to deduced the material properties of the lens using the lens deformation data obtained from the lens spinning tests.

Computational Methods:

A 2D asymmetric model representing the lens was constructed in COMSOL® from geometrical data extracted from lens spinning tests. COMSOL's® Structural Mechanics module and Nonlinear Elastic Material module are used to define the physics and associated material properties of the reconstructed porcine lens geometries as part of the development of the forward finite element analysis. Using the reconstructed un-deformed and deformed geometries of a tested porcine lens, both a forward and an inverse finite element analysis is performed using COMSOL Multiphysics® to estimate the shear modulus values of a tested porcine lens.

COMSOL's® Optimization Module using the Nelder-Mead algorithm is used to perform the inverse finite element analysis, employing a geometrical comparison of a simulated lens geometry (starting from the undeformed geometry results from study 1) with that of the deformed porcine lens geometry result from Study 2, to estimate the lens' shear modulus value which will minimize the difference between the two geometries, through the evaluation of an overall objective function shown in **Equation 1**.

The overall process methodology is shown in **Figure 3**.

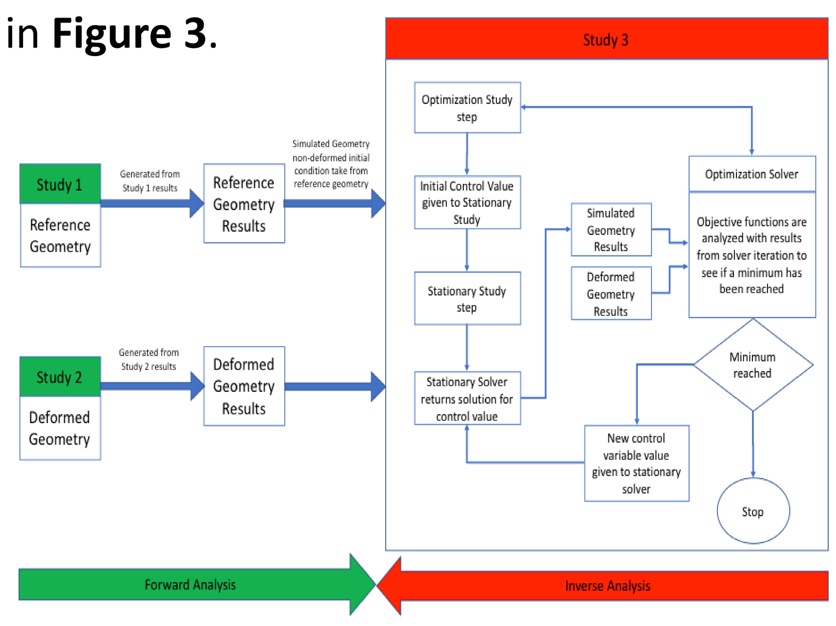


Figure 3. Overall Process Methodology [2]

$$Q(\xi) = \min\left[gobj_1(\xi) + gobj_2(\xi) + gobj_3(\xi) + gobj_4(\xi)\right]$$

Equation 1. Overall Objective Function [2]

As part of the set-up of the inverse analysis, four individual global objectives function are created, ***gobj$_1$***, ***gobj$_2$***), ***gobj$_3$***), and ***gobj$_4$***) as defined by **Equation 2**.

$$gobj_1 = \left(\left(\frac{s(\xi)}{S}\right) - 1\right)^2,\ gobj_2 = \left(\left(\frac{a(\xi)}{A}\right) - 1\right)^2,$$
$$gobj_3 = \left(\left(\frac{r(\xi)}{R}\right) - 1\right)^2,\ gobj_4 = \left(\left(\frac{z(\xi)}{Z}\right) - 1\right)^2$$

Equation 2. Individual Objective Functions [2]

The first objective function compares the arc length (*S*) of the deformed geometry, with the arc length (*s*) of the simulated geometry which is dependent of the control variable ξ (i.e. shear modulus of the lens). The second objective function compares the cross-sectional area (*A*) of the deformed geometry, with the cross-sectional area (*a*) of the simulated geometry which is dependent of the control variable of the lens. The third and fourth objective functions compare the deformed radial length (*R*) and axial length (*Z*) respectively, with the simulated radial length (*r*) and axial length (*z*), which are also dependent on the control variable. Each objective will go to zero when a perfect match between the simulated and deformed geometries occur for that particular objective (i.e., arc length, area, radial length, and axial length).

Results:

COMSOL's® Application Builder was used to create a custom GUI on top of the COMSOL ® simulation model, allowing the simulation application to be easily used, even by people with no expertise in FEA modeling and simulation. Users are able to easily upload lens spinning data into the application, start the analysis, and obtained the results with only a few button clicks. Some examples of GUI are shown in **Figure 4**.

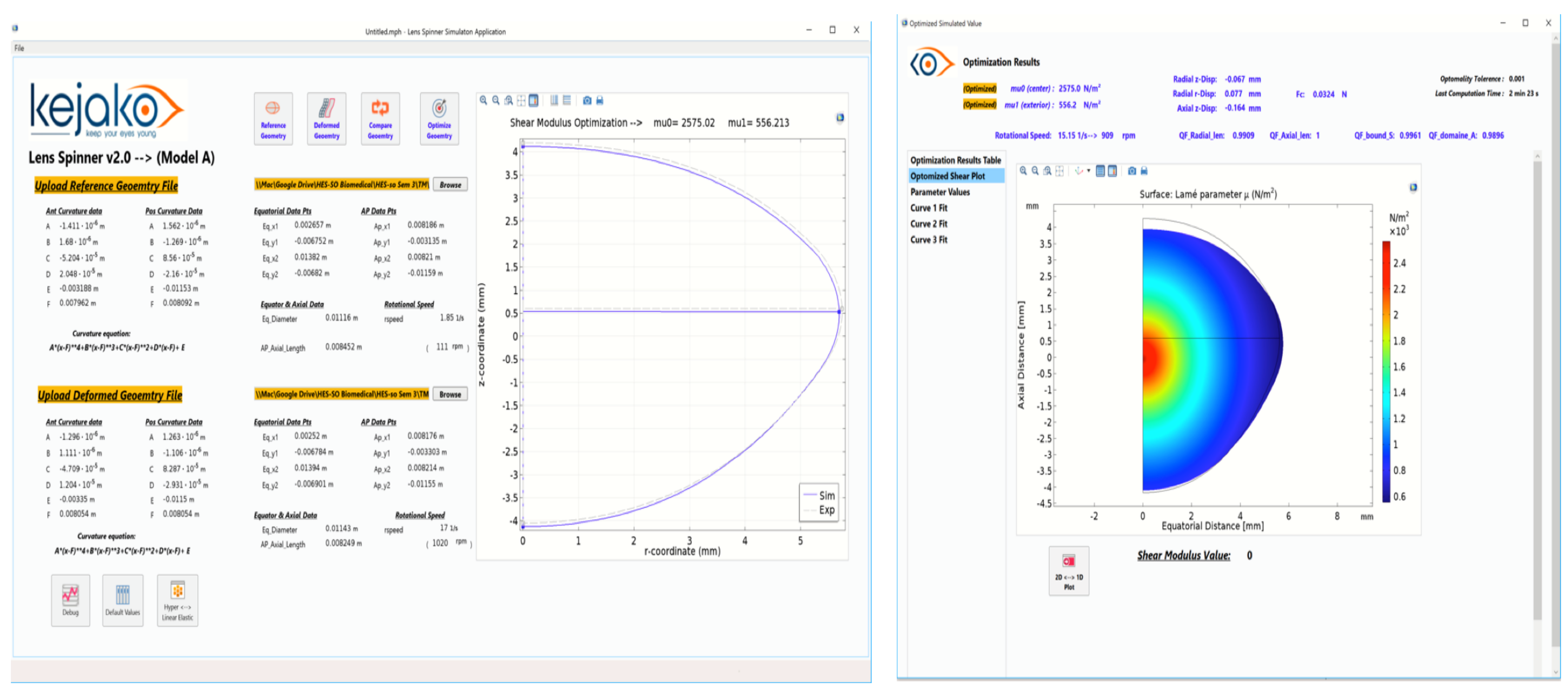


Figure 4. GUI Screenshots example of selected screens [2]

Conclusions:

Using COMSOL's® Application Builder to create a customized GUI is relatively easy and straightforward. Even for those who are not programming geniuses; using the Application Builder's graphical interface, allows even a novice to create a professional looking GUI. This tool is part of COMSOL's® standard modules package and makes the potential for sharing simulation models much easier, especially with potential end users that have no experience in FEA modeling and simulation. Moreover, building a GUI on top of the simulation lets the simulation engineer decide and control what potential users can view and how they can use the simulation application.

Even if there are no plans by a COMSOL® user of sharing their simulation model with others, there are still advantages for COMSOL® users to build GUIs for their models. A simple GUI can be quickly designed and implemented, thus allowing the COMSOL® user to efficiently and rapidly automate specific tasks or sequences, get or set parameter values, enable or disable different elements within the model, store derived values and results to variables, easily implement logical decision making, and easily interface with external resources.

References:

1. « Accommodation (eye) » Wikipedia, the Free Encyclopedia, Wikimedia Foundation, Inc, 17 June 2017, en.wikipedia.org/wiki/Accommodation_(eye). Accessed 2 Jan. 2018.
2. Kejako, Internal, David Enfrun, Aurélien Maurer, and John Speyrer, 2018
3. « COMSOL Multiphysics v 5.3 » COMSOL, 2017.